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An Investigation of Creosoting and Fireplace Inserts

December 1981

Sponsored by
U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Washington, DC 20234

and

U.S. Department of Energy
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U.S. Consumer Product Safety Commission
Washington, DC 20207

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AN INVESTIGATION OF CREOSOTING AND FIREPLACE INSERTS

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NOTICE

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Grant No. NB80NADA1012

Submitted to

National Bureau of Standards
Washington, D.C.

Submitted by

Department of Mechanical Engineering
Auburn University
Auburn, Alabama 36849

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1. Introduction

1.1. Background

The need for more economical means to heat homes has prompted a tremendous return to wood as a fuel for home heating. There are two traditional appliances used to burn wood in the home: the fireplace and the wood burning stove. Fireplaces provide a very cozy atmosphere in the home; however, in general they are not very energy efficient. Thus, fireplaces are generally not used as primary heating sources. Wood burning stoves, on the other hand, are much more energy efficient, generally at the expense of the aesthetic qualities of the fireplace. In addition, stoves usually rob the home of much more floor space than do fireplaces. Basically, the efficiency advantage enjoyed by stoves is due to the stove's abilities to control the flow of combustion air into the combustion chamber and to transfer the heat released to the home. Recently appliances that fit into a fireplace and make them operate in a manner similar to a stove have become widely available. These appliances are called fireplace inserts or fireplace retro-fit units.

Estimates indicate that there are between 15 and 30 million masonry fireplaces in existence. The use of fireplace inserts in the masonry fireplaces could provide primary heating sources for many of the homes in which they are located. In addition to the masonry fireplaces in existence, there are many factory-built fireplaces and fireplace shells in use. Fireplace inserts could improve the efficiency of most of these units, especially the so-called baseline or builder's model manufactured fireplaces.

Unfortunately the wide spread use of fireplace inserts could produce unsafe conditions in some installations. The most obvious problem areas are: (1) the formation of creosote in the flue system above the insert and the related chimney fire potential, and (2) the overheating of fireplaces and surrounding combustible materials due to hotter fires produced by fireplace inserts. Therefore, a test program was initiated to assess the potential safety problems related to the use of fireplace inserts. This test program was sponsored by the Center for Fire Research of the National Bureau of Standards and included two parallel efforts. One was conducted by Auburn University and is described in this report; the other was conducted by Underwriters Laboratories. The results of these tests will be most useful in formulating and evaluating test standards and building codes related to the safe utilization of this new type of appliance.

1.2. Objectives

The objectives of this test program were:

1. Identify the generic types of fireplace inserts currently available. (Auburn University)
2. Identify the generic types of fireplaces currently in use. (Underwriters Laboratories)
3. Carry out a test program to determine any unsafe features of the inserts or of the insert-fireplace combinations. (Auburn University and Underwriters Laboratories)
4. Analyze the testing results and provide information from which safety standards and codes can be developed. (Auburn University and Underwriters Laboratories)

The first objective involved canvassing the industry to collect information on fireplace inserts currently being manufactured. Each insert design was classified by important design characteristics to separate the appliances into generic types. The second objective was carried out by Underwriters Laboratories in a similar program to identify fireplace types:

both masonry and manufactured fireplaces were considered.

The third objective involved testing the generic types of inserts in various generic types of fireplaces. The test program was designed to identify safety problems that (1) might be inherent in the appliance, (2) might be caused by the installation of an insert in a particular fireplace, or (3) might be caused by the operation of a fireplace insert. The areas of concern were:

1. Creosoting - ability of the insert/fireplace combination to operate without producing unsafe amounts of creosote in the flue system.

2. Thermal Performance - ability of the insert/fireplace combination to maintain safe temperatures on both the appliance components and nearby combustible surfaces.

3. Contamination of Room Air - ability of the insert/fireplace combination to not allow carbon monoxide and other undesirable gases into the room.

4. Structural, Electrical, etc. - adequacy of the appliance's structural construction and suitability of electrical blowers, etc.

The first and second objectives were of primary concern. The tests conducted were not intended to be complete and exhaustive in nature, but rather to indicate those aspects of fireplace inserts and their utilization that may result in unsafe conditions. Results of the tests are reported in later chapters.

1.3. Outline of Report

The remainder of this report describes the work carried out during this study to determine the safety of fireplace inserts. Chapter 2 covers the review and classification of fireplace inserts. A description of the appliances used in the current study, both fireplaces and fireplace inserts, is included in Chapter 3. Chapter 4 discusses chimney creosoting. Several earlier studies are described for background information, and then the results of the present study are presented. Results of the thermal performance tests are presented in Chapter 5. Finally, conclusions and recommendations for future study are given in Chapter 6.

2. Fireplace Insert Design Review

2.1. Survey of Fireplace Inserts

Information was gathered for many of the fireplace inserts currently being marketed. Three methods were utilized to obtain this information.

The first method involved mailing out questionnaires to manufacturers of wood burning equipment. A copy of the questionnaire is included in Appendix A. Of the 147 manufacturers contacted, a response was received from 62 - nearly half of those contacted. Forty-seven of the manufacturers that responded to the questionnaire currently had fireplace inserts on the market. It is felt that the 47 responses represent the field of fireplace insert types.

The second method of identification was a publication from the Wood Energy Research Corporation entitled, "1980 Fireplace Insert Directory." [12] This publication provides minimum data on many units. Finally, data were also collected firsthand at major industry trade shows. Units were visually inspected and literature collected on units at the shows.

The only significant problem encountered was the precise definition of a fireplace insert. It was decided to exclude the following types of units:

* Those units intended to have masonry built around them; i.e., those not intended for use in an existing fireplace.
* Hearth stoves; i.e., room heaters placed on a fireplace hearth and merely ducted to the fireplace flue.
* Special grate and glass door assemblies.

These restrictions reduced the number of inserts identified in the survey to 35. Table 2.1 presents a summary of the information collected.

Table 2.1 Summary of Insert Data Collected

ENCLOSURE						DOORS			FLUE CONNECTOR				AIR INTAKE					CIRCULATING SYSTEM					FIREBOX				OUTER ENCLOSURE				DOORS					FLUE CONNECTOR			
MANUFACTURERS CODE	SINGLE BOX	BOX IN BOX	PROTRUDING ENCLOSURE	NUMBER OF INCHES	ANDIRONS OR GRATE	AIRTIGHT	SEMI AIRTIGHT	VERY LOOSE	NUMBER OF OPENINGS	SHAPE OF OPENINGS	LOCATION OF OPENINGS	AIRTIGHT CONNECTION	THERMOSTATIC CONTROL	MANUAL CONTROL	NUMBER OF INLETS	LOCATION OF INLETS	AIR THROUGH ASH GRATE	NATURAL OR FORCED	LOCATION OF FAN	# OF EXPOSED SIDES	BAFFLES OR DEFLECTORS	EXTRA H.T. SURFACE	PLATE ST. THICKNESS	CAST IRON THICKNESS	SHEET METAL THICKNESS	OTHER THICKNESS	PLATE STEEL THICKNESS	CAST IRON THICKNESS	SHEET METAL THICKNESS	OTHER THICKNESS	STEEL	CAST IRON	GLASS INSERTS	GASKET AROUND DOOR	OTHER	STEEL	CAST IRON	OTHER	NONE
A		*	*	8		*				RO	TR		*					BO	F	4	*		.19						.10		*			*					*
B		*				*			2	RE	TR			*	2	D		BO	F	5	*		.25				.10					*							*
C		*			*	*			1	RE	T			*	2	B		FO	F	0	*		.25				*					*		*					
D		*	*	V		*			1	RO	T	*		*	2	B		BO	F	4	*		.25				.13					*				*			
E		*					*		5	RO	T			*	6	B		BO	F	2			.19				.06						*						*
F		*	*	3.5	*	*			1	RE	RT			*	2	D	*	FC	R	3	*	*	.19				.13				*			*		*			
G		*	*	V	*		*		1	RE	T	*		*	4	D		BO	R	3	*				.25				.13	.25		*		*		*			
H		*					*		.1		T	*		*	10			NC		6			.25				.25				*		*	*		*			
I		*	*	8		*			1	RO	T							NC																		*			
J		*	*	6		*			1	RE	T		*		1	F		BO	F	5	*	*	.19						.10					*					
K	*	*			*		*		1	RE	T	*		*	3	B	*	BO	F	5	*		.13				.13				*		*			*			
L		*	*	7.5			*		1	RO	TR			*	8	D		FO	F	5			.25						.09		*					*			
M		*	*	9			*		1	SQ	T			*	2	F	*	BO		3	*		.13				.13				*		*			*			
N		*	*	11			*		1	RO	T			*	2	D		BO		6		*	.25				.25					*							*
O		*	*	12		*			1	SQ	T	*		*	2	D		FC	*	3	*	*	.25						.25			*	*	*					*
P		*	*	V		*			1	RO	TR			*	2	D		BO	B	5	*		.25				.19					*		*		*			
Q	*	*	*	25			*		1	RO	TP			*	2	D		BO		4	*		.25									*				*			
R		*		3	*		*		1	SQ	T		*		1	F		FC	F	0	*	*	.19			.25			.03		*		*			*			
S		*	*	9	*	*			1	RE	T			*				NC		5					.06	.06			.04		*		*		*	*			
T		*				*			1	RO	T	*		*	1	D		FC	B			*			.19				.09		*		*	*		*			
U		*	*	V		*			1	RE	T			*	1			FC		4	*		.25									*		*		*			
V	*					*			1	RO	TR	*		*	2	B		BO		4			.19				.13				*	*	*	*					*
W		*	*	V	*		*		1	RE	T			*	2	B		BO	B	2	*	*	.19								*					*			
X	*		*	V		*			1	RO	T			*	1	D		FC	S	T		*	.25		.11		.25		.11		*		*	*		*			
Y		*			*	*			1	RO	T		*		1		*	FC	F	4	*		.25									*	*	*		*			
Z	*					*			1	RO	R	*		*	2	D		BO	S	5	*			.25	.10				.10		*	*	*	*					*
AA		*	*	4	*	*			1	SQ	T	*		*	9	B		FC	S	5	*		.25				.10				*		*						*
BB		*			*		*		1	RE	TR			*	4		*	FC	F	4			.19				.25		.10			*				*			
CC		*		5		*			1	RE	T	*		*	2	S		FC	F	3	*	*	.11								*		*	*					*
DD	*				*	*		*	1	RE	TR			*	1	F		BO	F	0	*	*	.25						.10		*					*			
EE	*		*	9			*		1	RO	T	*		*	2	F		NC		3	*				.03				.09			*	*						*
FF		*	*	3.5			*		1	RE	T		*	6	D	*		BO	F	4	*		.19	.38	.12		.38		.12			*		*		*			
GG		*	*	11		*						*		*	3			FC	F	4	*	*	.13						.13		*								
HH	*					*				SQ	T		*		3		*	BO	F	4	*		.25				.19					*	*	*		*			
II		*	*	11		*			1	RO	T			*	2	D		NC					.19				.19					*	*						*
JJ		*	*	7	*	*			1	RE	T			*	8	D		NC	F	5			.125				.125				*					*			
KK		*	*	3		*			1	RE	T			*	2	D		FC	B	2			.25				.25				*		*						*
LL	*					*			1	RE	T			*	8	B	*	NC	F	0			.19				.19					*							*
MM		*	*	4		*			1	RE	T			*	6	D		FC	B	5																			

Note: All dimensions are given in inches.

LEGEND

V - Variable	F - Front	B - Bottom
RO - Rouno	FC - Forced Convection	T - Top
RE - Rectangular	NC - Natural Convection	R - Rear
SQ - Square	BO - Both Forced and Natural Convection	TR - Top Rear
D - Door	S - Side	RT - Rear Top

* Indicates a YES Response

2.2. Determination of Important Characteristics

Once the definition of a fireplace insert was settled, attention was focused on the determination of the characteristics that most affect creosote formation and safety of fireplace inserts. The fireplace insert questionnaire requested information concerning observable features of inserts that may be important to safety and creosote formation. The design of the firebox or enclosure was considered important because higher firebox temperatures were expected in fireplace inserts. The doors were considered important for two reasons: (1) they are a primary source of air leaks into most units, and (2) they make up a substantial portion of the surface area available for direct radiant heat transfer from fireplace inserts. The type, size, and location of the flue connector were thought to be of consequence, primarily in preventing the collection of debris behind the insert. Combustion air control and routing affect the efficiency of wood burning appliances, and thus are safety parameters. Heat that can not be transferred to the room can overheat the fireplace and nearby combustibles. Other features affecting heat transfer characteristics were noted because as an insert extracts more heat from the combustion gases, its efficiency increases; however, its creosoting potential also increases. The construction materials, material thicknesses, and construction details were also deemed important. After some deliberation five characteristics were chosen as being the most important for the purposes of this study:

(1) Single Box or Double Box Construction

This characteristic is primarily a safety consideration. A single box unit would be expected to transfer more heat to the fireplace walls creating higher temperatures than a double box unit. Since firebox temperatures of woodstoves are considerably higher than those of open fireplaces, this factor could become crucial.

(2) Airtight or Non-airtight

Airtight units should have better efficiencies than non-airtight units; but because the flow of combustion air is limited, the tendency to produce creosote may be increased greatly. Airtight inserts may also produce much higher flue gas temperatures.

(3) Glass Doors or Metal Doors

The effect of glass doors is not well understood. It is suspected that the glass doors may reduce the amount of heat transferred directly to the room, and thus, create higher firebox and flue temperatures. These higher temperatures should reduce the creosote formation, but the unit's safety and efficiency may suffer. This effect may also depend on the type glass used.

(4) Positive or Non-Positive Flue Connection

This characteristic is thought to be most important in creosote formation. By providing a positive connection between firebox and chimney, it should be easier to establish a draft. This should help prevent the stagnation and condensation of gases in a cold chimney. Also, any creosote that forms is more likely to run back into the firebox rather than collecting on the hearth behind the insert. However, the type of flue connection may also affect the temperatures in the chimney.

(5) Forced or Natural Convection Heating

Since a large part of a fireplace insert is enclosed in the fireplace, the type of air circulation system employed is very important for good heat transfer. The amount of heat transfer to the room can affect creosote formation, efficiency, and safety.

A complete study of these characteristics would involve testing 32 units in combination with each type of fireplace identified by Underwriters Laboratories. A testing program of this magnitude would be far beyond the scope or intention of this program. Therefore, some of the combinations were excluded. Since the airtightness of a unit is a relative quantity, and since most manufacturers have no real basis for comparison, the information obtained from the questionnaire in this area was not valid in most cases. In addition, the presence or absence of glass doors is expected to be a dominant factor in the airtightness of a unit. This reasoning was used to eliminate airtightness as a distinguishing characteristic.

2.3. Categorizing Inserts

The four remaining characteristics (single box or double box construction, glass or metal doors, positive or non-positive flue connection, and forced or natural convective heating) produced a total of sixteen categories of inserts. A review of the questionnaire responses and other sources on information showed that only ten of these categories represented actual inserts. Table 2.2 contains a categorical listing of all inserts identified. Inserts from categories 2, 10, 13, 14, and 15 were chosen as representatives of the field. It was decided that by testing inserts from these five categories, the relative importance of each of the four characteristics specified could be evaluated. Also, these five categories contained approximately 75% of the inserts identified.

2.4. Summary

The first step in classifying fireplace inserts was to formulate a precise definition of a fireplace insert. The following definition was adopted:

> "A fireplace insert is a space heating device with a self-contained firebox designed to burn solid fuels and intended to be installed in an existing fireplace. A fireplace insert is intended to be operated with the fuel loading and ash removal openings closed so as to maintain some control of the air flow into the fire chamber."

Using this definition to narrow the field, inserts were then classified according to the following four observable physical characteristics:

(1) Single box or double box construction

(2) Glass or metal doors

(3) Positive or non-positive flue connection

(4) Natural or fan forced convective heating.

Table 2.2 Categorical Listing of Fireplace Inserts

#	IMPORTANT CHARACTERISTICS	UNIT IDENTIFICATION
1	SB, PF, FC, GD	Z
2*	SB, PF, FC, GD	V, EE
3	SB, PF, NC, GD	
4	SB, PF, NC, MD	
5	SB, NPF, FC, GD	X, DD
6	SB, NPF, FC, MD	
7	SB, NPF, NC, GD	LL
8	SB, NPF, NC, MD	
9	DB, PF, FC, GD	K, O, T, AA
10*	DB, PF, FC, MD	D, G, CC, GG, KK
11	DB, PF, NC, GD	
12	DB, PF, NC, MD	H
13*	DB, NPF, FC, GD	E, L, R, U, W, Y, BB, FF, MM
14*	DB, NPF, FC, MD	A, B, C, F, J, L, N, P, Q, HH
15*	DB, NPF, NC, GD	S, II
16	DB, NPF, NC, MD	I, JJ

LEGEND

SB - Single Box Construction

DB - Double Box Construction

FC - Forced Convection

NC - Natural Convection

PF - Positive Flue Convection

NPF - Non-Positive Flue Convection

GD - Glass Doors

MD - Metal Doors

*Designates representative categories to be tested.

3. Fireplaces and Inserts Used in Test Program

3.1. Fireplaces

Underwriters Laboratories performed a design review of both masonry fireplaces and manufactured fireplaces. The results of this review are presented by Terpstra and Jorgenson [14]. Based on this review Underwriters personnel designed a minimal masonry fireplace for use in the test program. This minimal masonry fireplace just meets the minimum of the various building code requirements, and thus, should represent a worst case host fireplace as described by Terpstra and Jorgenson [14]. Drawings of this fireplace and its enclosure are shown in Appendix B.

Two manufactured fireplaces were also used in the test program. Thermal tests were run in one manufactured fireplace, and creosote tests were run in both of the units. The fireplace used for the creosote tests, No. F1 as identified by Terpstra and Jorgenson [14], had a 21 inch high by 36 inch wide frontal opening and 320 square inches of hearth area. The insulated firebox was equipped with a means of heating room air by natural convection. A 9 inch diameter, triple wall, thermal siphon chimney was used to exhaust the combustion products.

The fireplace used primarily for the thermal tests, No. F2, had a frontal opening 27 inches high and 36 inches wide and a hearth area of 550 square inches. The firebox was insulated and had no means to convect heat to the room. The triple wall, thermal siphon chimney was 9 inches in diameter. Other manufactured fireplaces were used by Underwriters Laboratories to perform similar thermal tests.

3.2. Inserts

Chapter 2 described a design review of fireplace inserts. Six different inserts were used in the test program. These shall be referred to as inserts No. 1, 2, 3, 4, 5, 5C, and 6. Note that insert No. 5 was installed in two different configurations. Table 3.1 describes the inserts used in the test program. Additional inserts were tested by Underwriters Laboratories.

Table 3.1 Description of Inserts Used in Tests

Insert No. 1	This unit was a type 13 unit (Table 2.1). It had a double box construction, forced convective heating, glass doors, and a non-positive flue connection. The unit had 400 square inches of hearth area and was made of plate steel.
Insert No. 2	This unit was a type 16 unit (Table 2.1). It had a double box construction, neutral convective heating, metal doors, and a non-positive flue connection. The unit had 400 square inches of hearth area and was constructed of plate steel.
Insert No. 3	This unit was a type 16 unit (Table 2.1). It had a double box construction, natural convective heating, metal doors, and a non-positive flue connection. This unit had 460 square inches of hearth area and was constructed of plate steel.
Insert No. 4	This unit was a type 7 unit (Table 2.1). It had a single box construction, no convective heating (except off front), glass doors, and a non-positive flue connection. The unit had 330 square inches of hearth area and was made of plate steel.
Insert No. 5	This unit was a type 14 unit (Table 2.1). It had a double box construction, forced convective heating, metal doors, and a non-positive flue connection. The unit had 140 square inches of hearth area and was made of plate steel.
Insert No. 5C	This unit was Insert No. 5 installed with a positive flue connection, hence it was a type 12 unit (Table 2.1).
Insert No. 6	This unit was a type 13 unit (Table 2.1). It had a double box, forced convective heating, glass doors, and a non-positive flue connection. The unit had 450 square inches of hearth area and was made of plate steel.

4. Creosote

4.1. Introduction

The cost of home heating has increased sharply over the last five years; hence, heating residences with wood-fired appliances has gained popularity rapidly. Today there are many types of fireplaces, wood burning stoves, and wood burning furnaces available for home heating. In addition, there are many accessories for the basic units: accessories to improve the performance and to make units safer. Fireplace inserts are one type accessory for fireplaces. Along with the renewed interest in burning wood, there is also growing concern over the safety and efficiency of wood heating equipment. Creosote production and the resulting chimney fires are a major safety problem related to the use of wood burning appliances.

When wood is burned in a stove or fireplace, the combustion process occurs in stages. First, the moisture in the wood is driven off as the wood is heated. Next, the pyrolysis begins and volatile matter is released. Finally, the carbon or charcoal left by the first two stages is burned. These stages of combustion occur more or less simultaneously in wood burning equipment. Different pieces of wood are in the various stages of combustion at a given instant. It is the burning of the volatile gases that gives rise to the long flame. If not completely burned, these combustible gases are carried up the chimney. Such incomplete combustion may be a result of insuffient combustion air, inadequate mixing of the fuel and air within the combustion zone or too low temperatures in the combustion zone. Most residential wood burning equipment is subject to incomplete combustion during all or part of the burning cycle. If the temperature of the flue gases is reduced to the "creosote dew point," these volatile matters, "creosote," will be deposited on the inside surfaces of the chimney. The "creosote dewpoint" is approximately 300°F. The conditions for condensation of the unburned products to occur depends on the local temperature of the flue gases, the temperature of the chimney walls, and the amount of a particular species present in the flue gases. The condensate drips down the chimney walls and dries. This is creosote -- a sticky, black substance that is flammable. Thus, creosote is formed in the combustion process as a result of incomplete combustion and is deposited in the chimney via a condensation process.

It is observed that creosote is acidic with a PH value of about 4, and it has a heating value slightly less than that of wood tar, approximately 10,000 BTU/lbm. Creosote is corrosive to iron, steel, and even galvanized steel. Also, creosote has a significant insulating effect which can reduce the heat transfer from the stove to the room when it forms on the heat transfer surfaces. This may well lower the energy efficiency of the appliance as well as provide a potentially unsafe condition.

The composition of the products of wood distillation, shown in Table 4.1 gives some idea of the complexity of burning wood. This table also shows the composition of the compound creosote which is different from the composition of the material found in a typical chimney. Thus, the term "creosote," as applied to wood burning equipment refers to all the compounds that are condensed or collected in the chimney. Most of the 200 or more compounds in "creosote" are polycyclic aromatic hydrocarbons. Of these 200 or more compounds, less than 20 are present in amounts greater than one percent, [5]. The major components of creosote are listed in Table 4.2.

To reduce or eliminate the formation of creosote in wood burning

Table 4.1 Products of Wood Distillation [11]

1. <u>Hygroscopic Water</u>

2. <u>Gas, consisting mainly of</u>

   a. Acetylene
   b. Ethylene
   c. Benzol
   d. Naphtalene
   e. Carbon monoxide
   f. Carbon dioxide
   g. Methane
   h. Hydrogen

3. <u>Liquid tar, consisting of</u>

   a. Benzol
   b. Naphtalene
   c. Paraffin
   d. Retene
   e. Phenol

3. <u>Liquid tar (continued)</u>

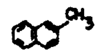
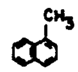
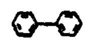
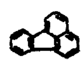
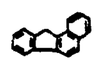
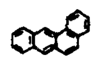
   f. Oxyphenic acid
   g. Crysylic acid
   h. Phlorylic acid $C_7H_8O_2$
   i. Creosote $C_8H_{12}O_2$
   j. Resins

   Phroligneous acid, consisting of

   a. Acetic acid
   b. Propionic acid
   c. Acetone
   d. Wood alcohol

4. <u>Wood Charcoal</u>

Table 4.2 Major Components in Creosote

Peak Number	Component	Whole Creosote	Boiling Point[1]	Melting Point[1]	Structural Formula	Molecular Weight
		Approx. Pct. ±0.7%	°C. 760	°C.		
1	Naphthalene	3.0	218	80.55		128.2
2	2-Methylnaphthalene	1.2	241.05	24.58		142.2
3	1-Methylnaphthalene	.9	244.64	-22		142.2
4	Biphenyl	.8	255.9	71		154.2
5	Dimethylnaphthalenes	2.0	268	7.66, 105	———	156.2
6	Acenaphthene	9.0	279	96.2		156.2
7	Dibenzofuran	5.0	287	86-87		168.2
8	Fluorene	10.0	293-295	116-117		166.2
9	Methylfluorenes	3.0	318	46-47	———	180.2
10	Phenanthrene	21.0	340	101		178.2
11	Anthracene	2.0	340	216.2-.4		178.2
12	Carbazole	2.0	355	247-248		167.2
13	Methylphenanthrenes	3.0	354-355	65-123	———	192.2
14	Methylanthracenes	4.0	360	81.5-209.5	———	192.2
15	Fluoranthene	10.0	382	111		202.3
16	Pyrene	8.5	393	156		202.3
17	Benzofluorenes	2.0	413	189-190		216.3
18	Chrysene	3.0	448	255-256		228.3

[1]Values from Handbook of Chemistry and Physics, 1971-72, 52nd ed., Chemical Rubber Publishing Co., Cleveland, OH.

appliances, one must first understand the factors that affect creosote formation. The parameters that affect creosote formation include:

(1). the wood species,

(2). the wood geometry,

(3). the wood moisture content,

(4). the stove's air inlet setting (air/fuel ratio at which the appliance is operating),

(5). the temperature of the combustion process,

(6). the completeness of mixing of the fuel and air in the combustion chamber,

(7). the temperature of the flue gases,

(8). the chimney wall temperature,

(9). the chimney wall roughness,

(10). the size of the chimney (expecially abrupt changes in the chimney size),

(11). the height of the chimney,

(12). the ambient temperature and humidity,

(13). the rate of wood consumption,

(14). the type of stove.

It should be kept in mind that there is a tremendous interrelationship between these factors. Hence, it is very difficult to determine the effect of each parameter individually.

4.2. Experimental Studies

A number of experiments have been conducted at the Auburn Wood Burning Laboratory to study the effect of wood type and wood moisture content on creosote formation in different types of stoves. A summary description of these tests and results is given below.

4.2.1 First Creosote Study

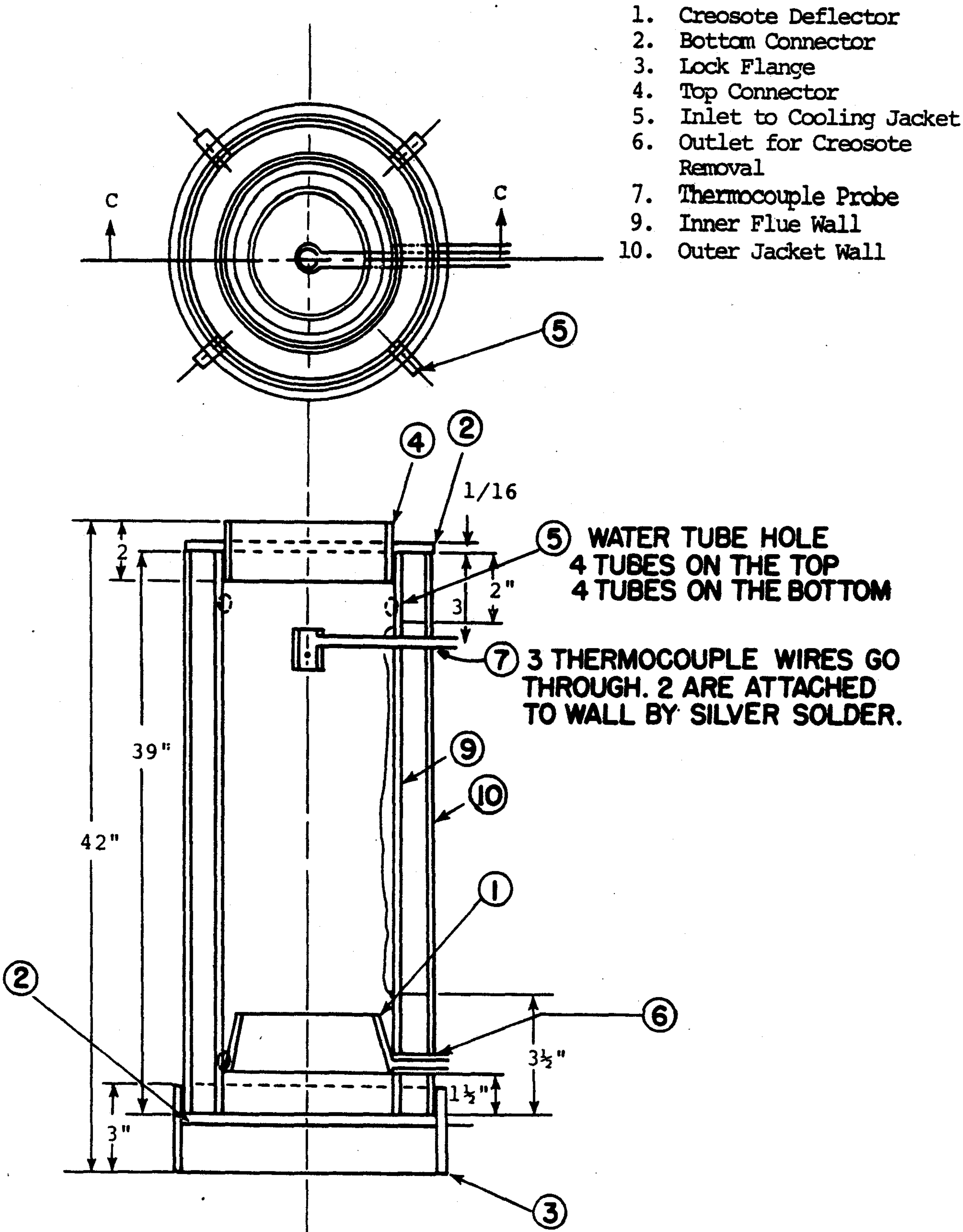
4.2.1.1. Test Facility

A special test chimney of double wall construction was built. This double wall construction provided a jacket of cooling water or steam to control the chimney wall temperature during a test and to reheat the chimney wall when the test was completed. The test chimney was made of 1/16-inch thick, type 304 stainless steel. Three sections of the chimney were constructed. Each section was formed from a six-inch diameter inner pipe and an eight-inch diameter outer pipe that were 39 inches long. Figure 4.1 shows the details of one section of the test chimney.

Water/steam manifolds (1/32-inch, type 304 stainless steel) were connected to the bottom and top of each chimney test section. Water was introduced at the bottom of each test section and allowed to exit at the top to ensure that the water jacket remained filled. When steam was utilized it entered the top of each section and exited the bottom to ensure that section contained only steam during the heating period. Also, it can be seen in Figure 4.1 that a truncated cone was placed inside the chimney to collect the creosote-water solution that condensed. This mixture was diverted through a 1/32-inch diameter tube to the outside of the eight-inch diameter pipe. The tube was connected to a collection beaker.

Flanges were welded on each end of the chimney sections to facilitate connecting the section together. Figure 4.1 also shows that three Type K thermocouples were placed at various locations to monitor the chimney wall and flue gas temperatures. Shielded thermocouples were used to measure the flue gas temperature.

The entire chimney assembly is shown in Figure 4.2. Figure 4.3 shows



SECTION CC

Figure 4.1 Details of Test Section

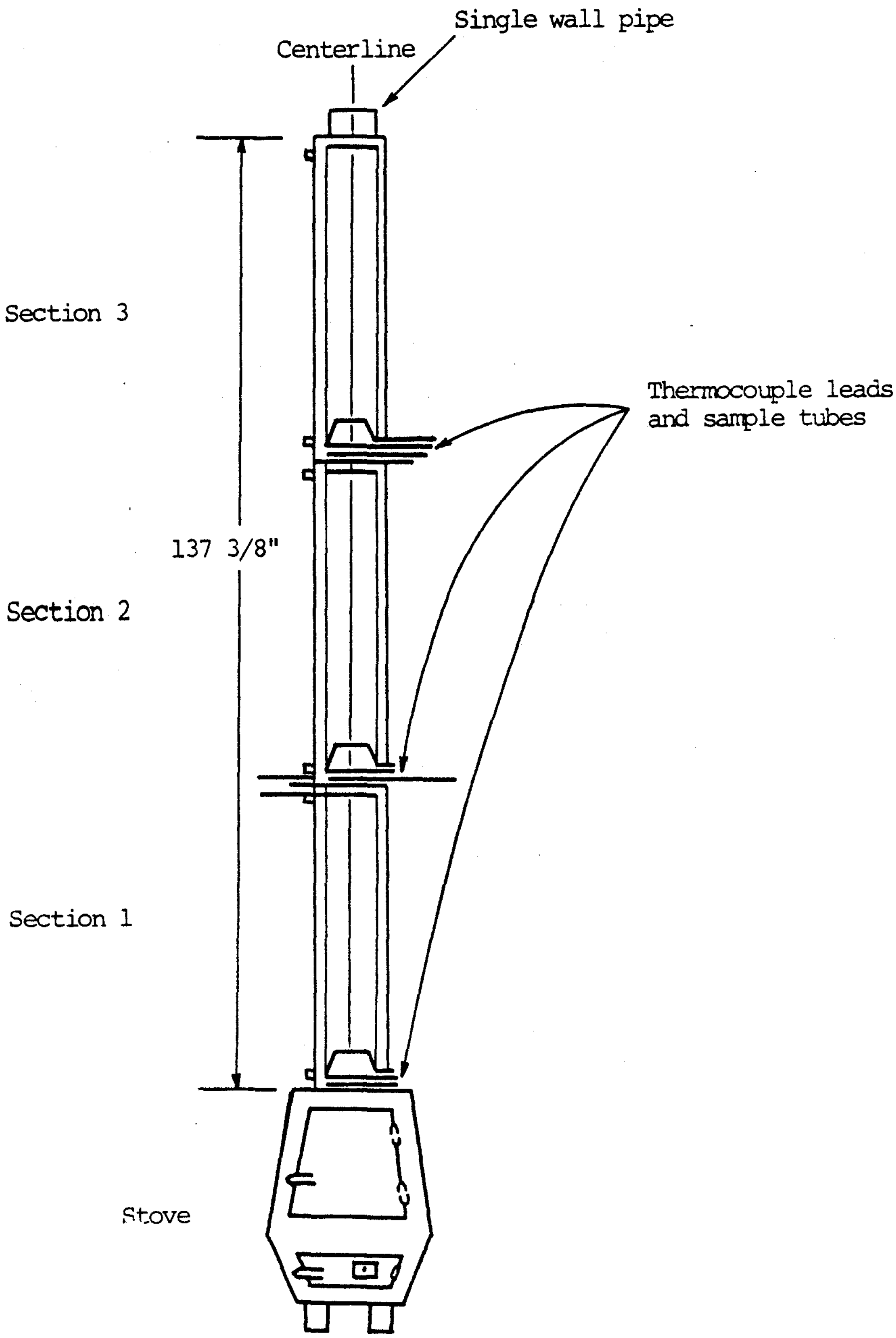


Figure 4.2 Assembly of Test Facilities

the water/steam circulation and control system. Photographs of the test setup and stove are shown in Figures 4.4 and 4.5. Figure 4.6 shows the necessary plumbing connection of the test sections. The creosote collection tube and the water manifold on the middle test section is shown in Figure 4.7. A length of 1/4-inch copper tube in which five Type K thermocouples were inserted and projected from five differently positioned holes was placed between the stove exit and lower test section to measure the flue gas temperature. A schematic diagram of the five thermocouples is shown in Figure 4.8.

All temperatures were recorded automatically by a data acquisition system. The test chimney was connected to a stove and the entire apparatus was situated on a digital balance so that the weight of wood consumed could be monitored. A hydraulic gas sampler collector and ORSAT gas analyzer were used to collect flue gas samples and analyze the CO_2, O_2, and CO content of the gas. A standard spectrophotometer was used to determine the concentrations of the creosote-water mixture collected during the tests. Details of the test chimney and instrumentation are given in references [8, 10, and 16].

4.2.1.2. Test Procedure

First, wood samples of the desired species, geometry and moisture content were prepared. Hickory, oak, and yellow pine at two different moisture contents and in three different geometries were used in the first series of tests. Figure 4.9a shows a standard configuration brand used. These brands were made of 3/4 inch by 3/4 inch strips attached in a grid pattern on one inch centers. A Type B brand is shown in Figure 4.9b. These brands were made of 3/4 inch by 1 3/4 inch strips on 2 1/4 inch centers. Figure 4.9c shows the split logs used. Each split log had an average surface area of

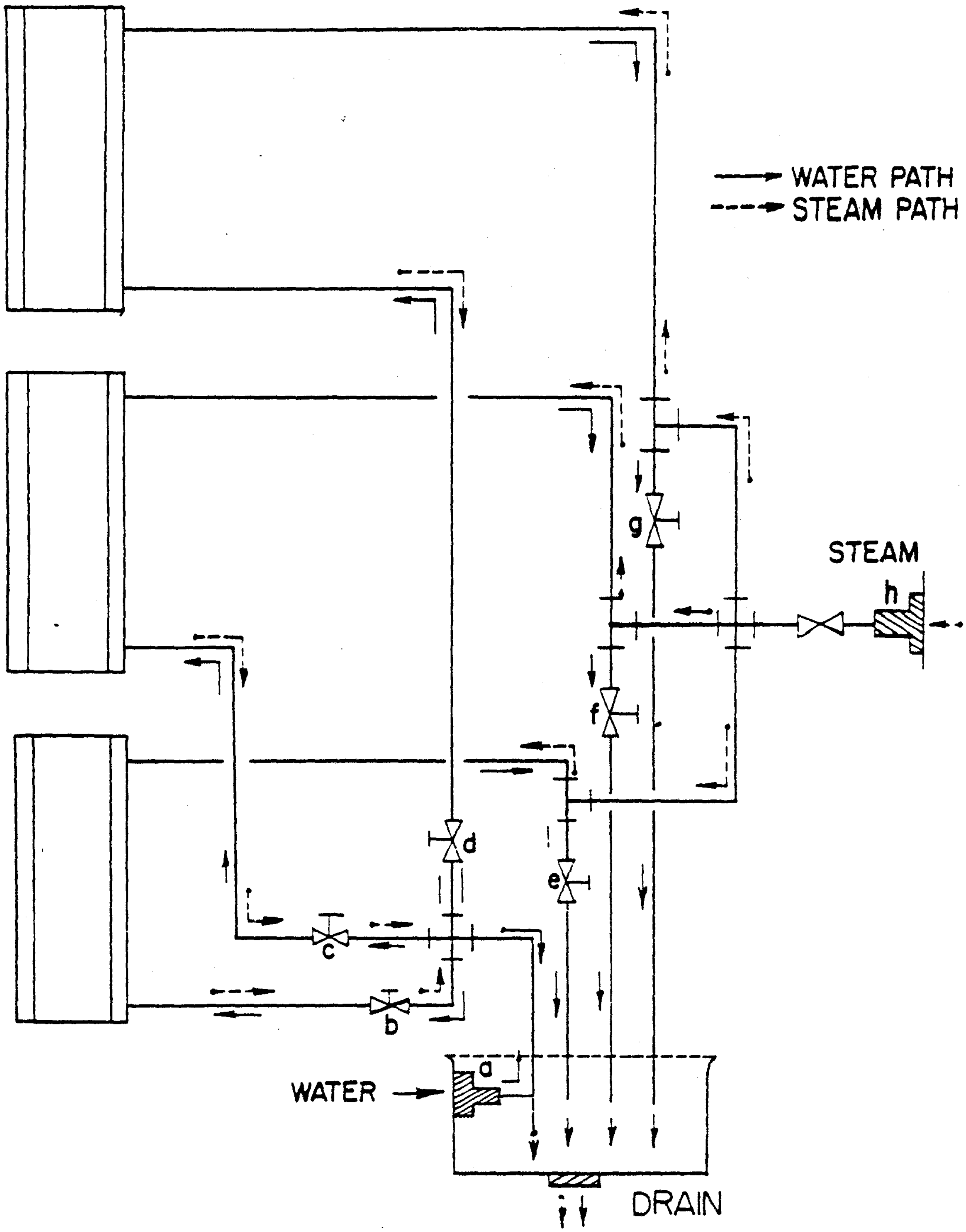


Figure 4.3 Water/Steam Circulation and Control System

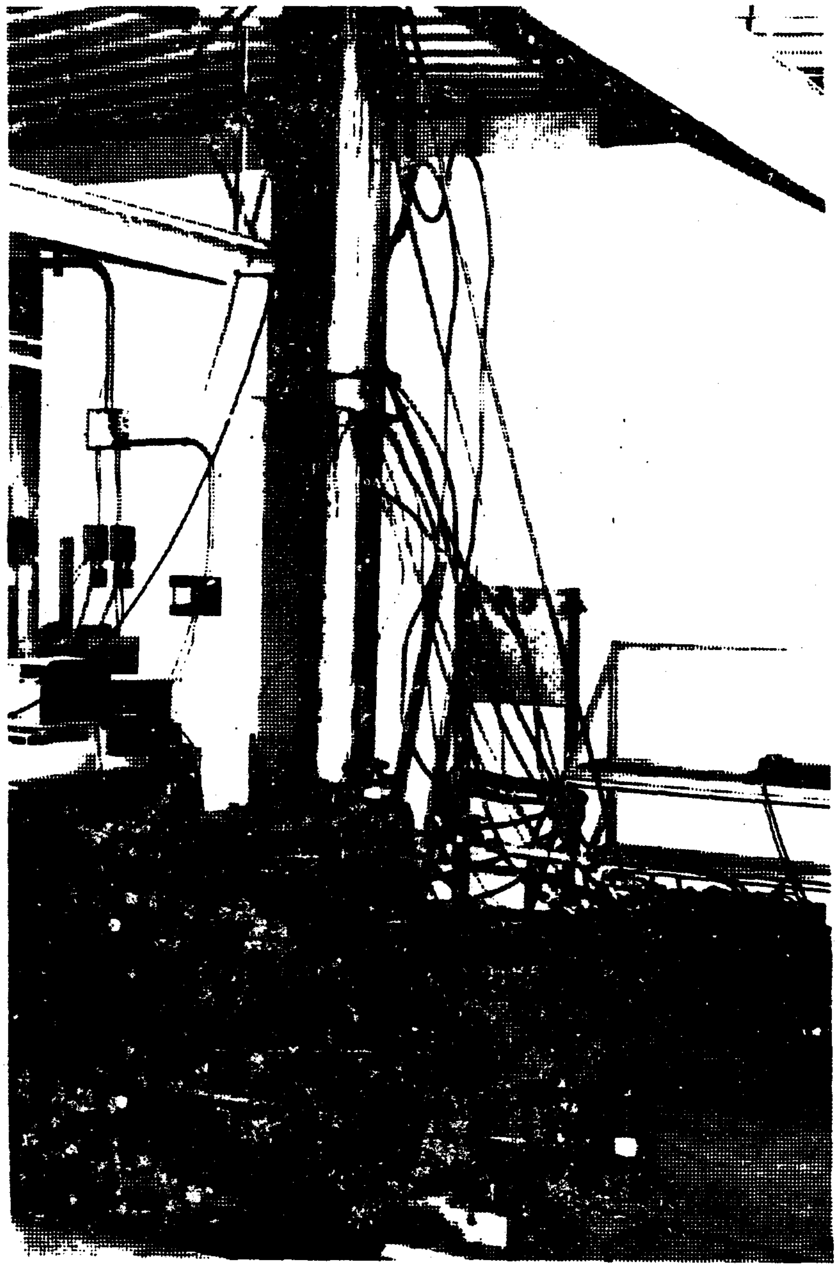


Figure 4.4 Test Installation

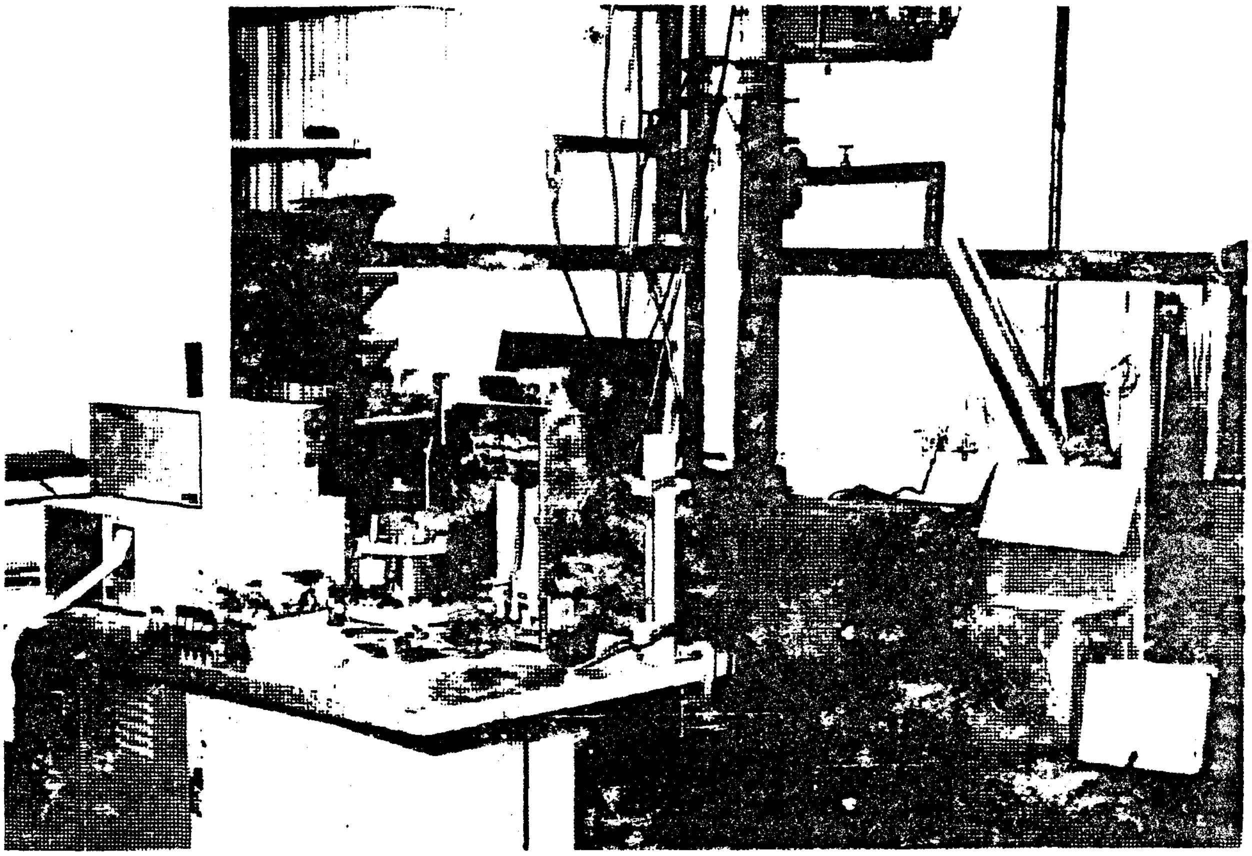


Figure 4.5 Entire Test Facilities

Figure 4.6 Water/Steam Plumbing at Test Sections

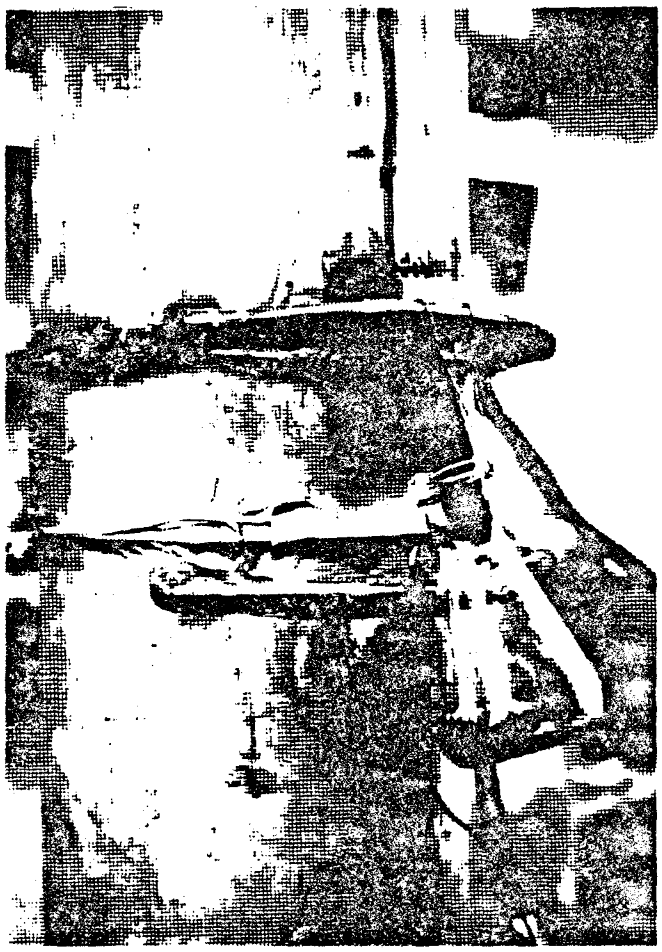


Figure 4.7 Collection Tube and Water Manifolds in Middle Section

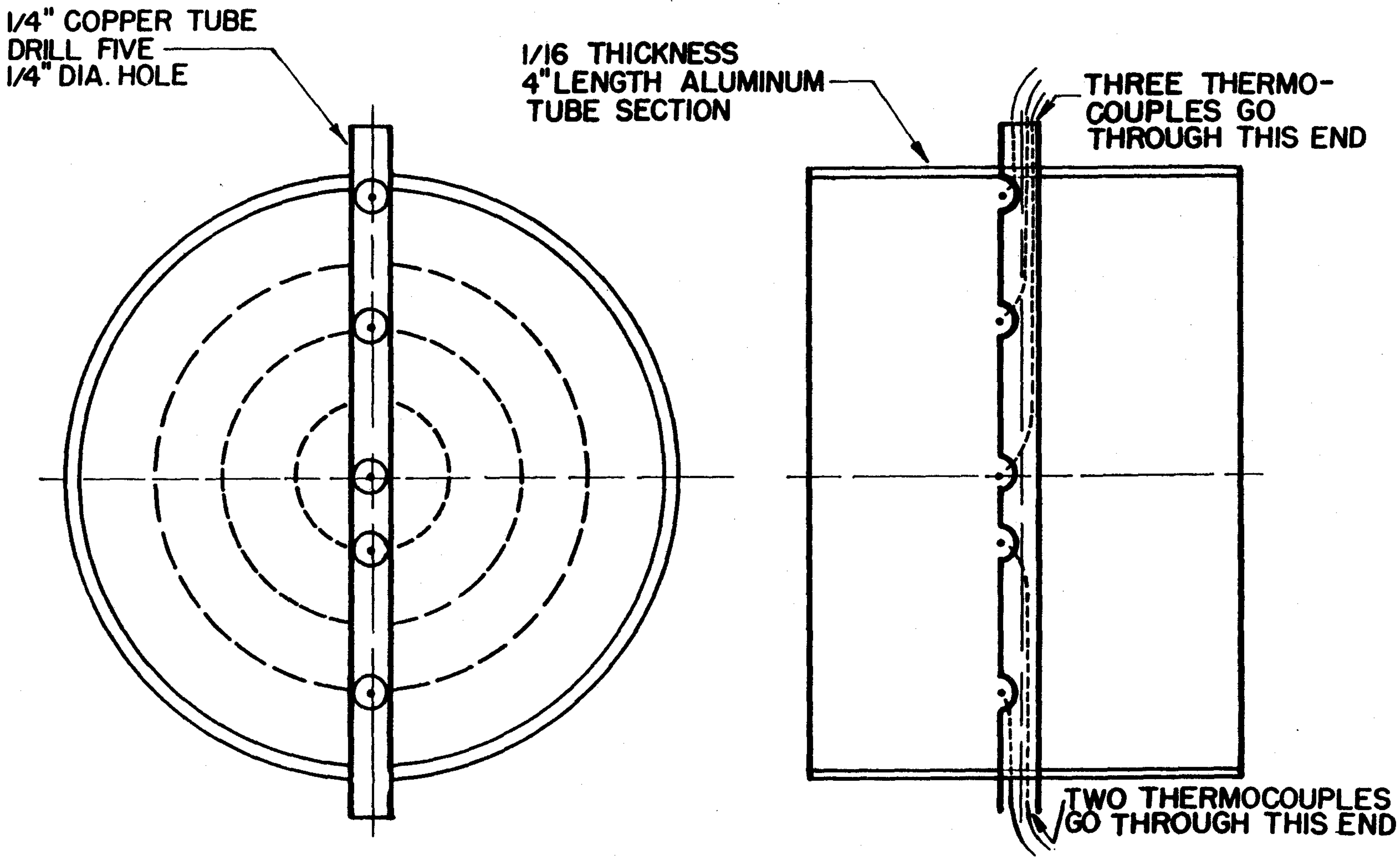


Figure 4.8 Design of Temperature Measurement at
Stove Exit

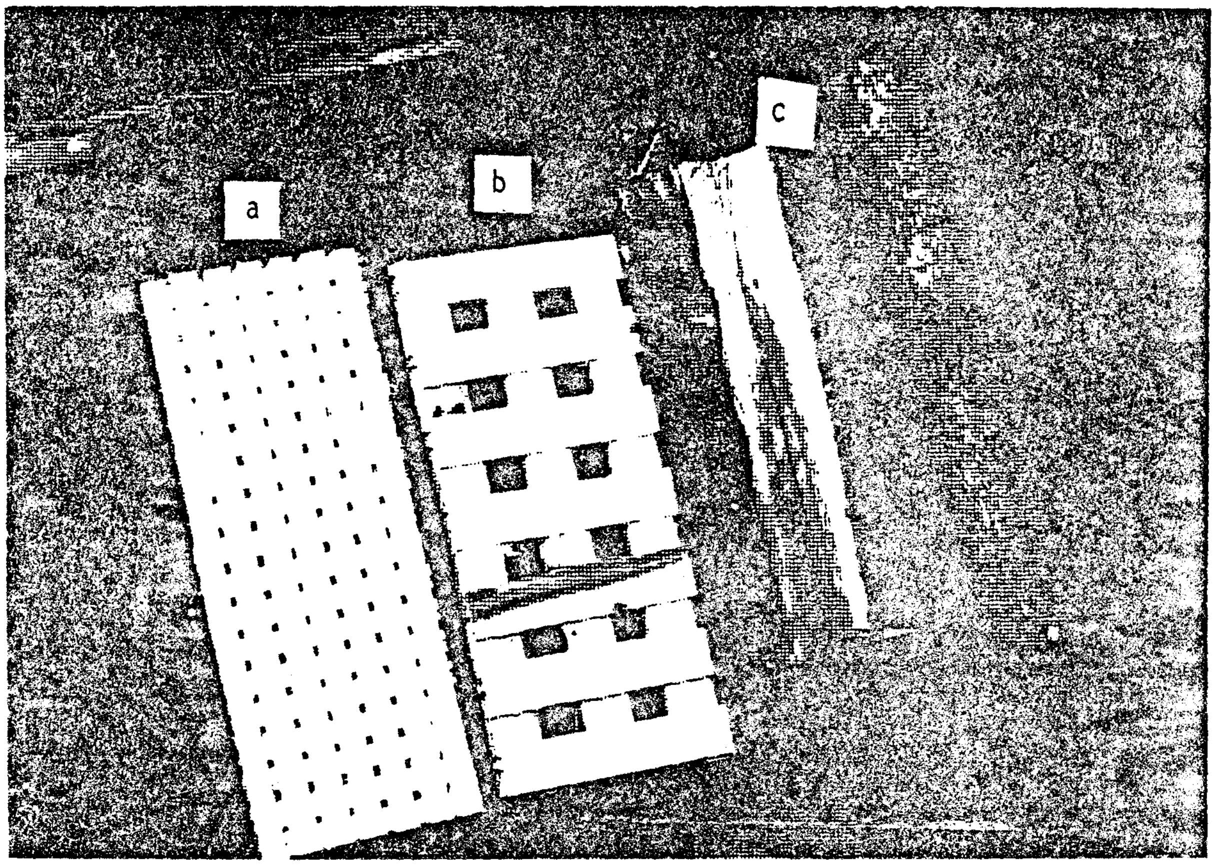


Figure 4.9 (a) Standard Brands, (b) Type B Brands, (c) Logs

about 280 square inches, the standard brands had a surface area of approximately 610 square inches and the Type B brands had a surface area of approximately 414 square inches. Oven dry brands and logs were obtained by placing the wood in an oven at 212°F for 72 to 168 hours (longer times were needed for the larger pieces) until no measurable weight change was detected. The moisture contents of the other fuels were determined by oven-drying a known weight of sample from the fuel and reweighing the sample after drying.

The test procedure is outlined below:

(1) Connect water/steam pipes to chimney. Check water and steam control valves.

(2) Ready data acquisition equipment (temperature readout), ORSAT gas analyzer and gas sample collector.

(3) Fire stove to build up bed of coals. This generally required at least a half-hour of operating time to bring the system up to temperature.

(4) Set combustion air inlet to desired position for run.

(5) Open and adjust chimney cooling water valves to obtain the same flow rates in each of the three chimney sections.

(6) Record initial stove weight and load fuel charge.

(7) Begin data collection. Temperature data and weight readings were recorded on five-minute intervals. ORSAT data for the flue gases were taken every ten minutes.

(8) When the wood was consumed, the test was ended.

(9) Close water valves. Open steam valves to reheat dry creosote left in test section.

(10) Close steam valves after twenty minutes of reheating.

(11) Measure volumes of creosote/water mixture collected from each chimney section.

(12) Stir mixtures and take samples for spectrophotometer analysis.

(13) Pour out the mixture, measure the amounts of heavy creosote deposited on the bottoms of the beakers.

This procedure was used to collect data on the creosote production and efficiency of the stove under various conditions.

4.2.1.3. Data Collection and Analysis

As noted the three types of wood used in this testing program were yellow pine, oak, and hickory. Yellow pine is a softwood with a relative density of about 29 pounds per cubic foot (dry basis), and oak and hickory are hardwoods with relative densities of about 41 and 44 pounds per cubic foot (dry basis), respectively. The moisture contents of the fuels used in the eighteen test runs are shown in Table 4.3.

The efficiency of the stove is defined as the percentage of energy released from the wood that is made available to heat the room. The efficiency was determined by the indirect or ORSAT method. The measurements needed to determine the efficiency are the flue gas temperature, the flue gas composition, and the rate of fuel consumption (wood mass loss). A shielded thermocouple and an automatic data acquisition system were used to measure the flue gas temperature. Weight readings were taken manually as needed. An ORSAT gas analyzer was used to obtain the levels CO_2, O_2, and CO in the flue gases leaving the stoves. By applying mass and energy balances using the data taken as described above, the efficiency of the unit was computed. The computational methods are described in References [3 and 15].

The flue gas temperatures and cooling surface temperatures at various locations in the chimney were recorded automatically. Flue gas temperatures at the stove exit were measured every five minutes and an average temperature was calculated.

Finally, the relative concentrations of creosote mixtures were determined with a spectrophotometer. The spectrophotometer is a device that

Table 4.3 Moisture Contents of Test Woods

No.	Wood Type	Geometry	Moisture Content (%)
1	Pine	Standard Brand	0.0
2	Pine	Brand B	0.0
3	Pine	Log	0.0
4	Pine	Standard Brand	8.3
5	Pine	Brand B	8.3
6	Pine	Log	42.0
7	Oak	Standard Brand	0.0
8	Oak	Brand B	0.0
9	Oak	Log	0.0
10	Oak	Standard Brand	28.0
11	Oak	Brand B	28.0
12	Oak	Log	26.0
13	Hickory	Standard Brand	0.0
14	Hickory	Brand B	0.0
15	Hickory	Log	0.0
16	Hickory	Standard Brand	27.0
17	Hickory	Brand B	27.0
18	Hickory	Log	25.0

passes light through a substance and measures the optical density of the substance. The Beer-Lambert Law [11] states that the light absorption is proportional to the concentration of the absorbing substance through which the light passes. This can be stated mathematically as follows:

$$A = E\,c\,l$$

Where A is the absorption of the light

E is an extinction coefficient or optical absorptivity for the substance

c is the concentration of the substance

l is the length of the light path (1 cm standard).

The substance of interest is dissolved in a transparent solvent (i.e., water); thus, the concentration in the above equation refers to the concentration of the substance of interest (the creosote) in the solvent.

The creosote samples collected were diluted with water at a ratio of 9 parts water to 1 part creosote sample. The absorption or optical densities of the samples were then determined with 450 nm wavelength light. Then to compare the relative amounts of creosote in each sample, a Creosote Number was defined.

$$\text{Creosote Number} = \frac{\text{(Relative Optical Density) (Volume of sample)}}{\text{Mass of dry wood consumed}}$$

Thus, the Creosote Number is a normalized measure of the opacity or optical density of the solution of creosote sample and solvent. The optical density is related to the concentration of creosote substances in the solution, and hence, to the amount of creosote present. The Creosote Number does not give a quantitative measure of the amount of creosote produced, but it does passes light through a substance and measures the optical density of the substance. The Beer-Lambert Law [11] states that the light absorption is proportional to the concentration of the absorbing substance through which the light passes. This can be stated mathematically as follows:

$$A = E\,c\,l$$

Where A is the absorption of the light

E is an extinction coefficient or optical absorptivity for the substance

c is the concentration of the substance

l is the length of the light path (1 cm standard).

The substance of interest is dissolved in a transparent solvent (i.e., water); thus, the concentration in the above equation refers to the concentration of the substance of interest (the creosote) in the solvent.

The creosote samples collected were diluted with water at a ratio of 9 parts water to 1 part creosote sample. The absorption or optical densities of the samples were then determined with 450 nm wavelength light. Then to compare the relative amounts of creosote in each sample, a Creosote Number was defined.

$$\text{Creosote Number} = \frac{(\text{Relative Optical Density})\ (\text{Volume of sample})}{\text{Mass of dry wood consumed}}$$

Thus, the Creosote Number is a normalized measure of the opacity or optical density of the solution of creosote sample and solvent. The optical density is related to the concentration of creosote substances in the solution, and hence, to the amount of creosote present. The Creosote Number does not give a quantitative measure of the amount of creosote produced, but it does provide a means of qualitatively comparing the amount of creosote produced for the various conditions.

Table 4.4 shows the results of the spectrophotometer analysis. Note that the Creosote Number increases with the amount of creosote formed.

4.2.1.4. Results

The test results are presented to compare the effects of variations in moisture content of the wood, type of wood, and geometry of the wood on the production of creosote. The test data is summarized in Tables 4.5 and 4.6, and a discussion of each individual test run is given in Reference [8]. The three parameters that were chosen in the eighteen experimental tests are discussed below. All of the data shown were taken on the same radiant stove.

Effect of Moisture Content of Wood

The tests indicate that dry wood produces more creosote than wet wood under the same test conditions (see Figure 4.10). There are two reasons for this phenomena:

(1) The water-gas reaction. The volatile matters and water vapor generated in the inner portion of the wood must pass through the surface layers as they are transported out of the wood. It is possible that water vapor can react with charcoal when it passes through the external layers of wood to produce carbon monoxide and hydrogen gases. These additional combustible gases could result in secondary combustion [11]. This reaction has little effect on the thermal efficiency, for when water reacts with charcoal, it consumes heat (endothermic) to produce gases. However, when these gases react with oxygen, they produce heat (exothermic), water and carbon dioxide. It is possible that this additional secondary combustion might aid in the

Table 4.4 Results of Spectrophotometer Analysis for First Set of Tests

Test Number	Fuel	Volume of Mixture (ml) 1-sec	2-sec	3-sec	Optical Density (450 nm) 1-sec	2-sec	3-sec	Wood Consumed (lbm)	Creosote Number
1	Wet Pine Standard Brand	1500	700	225	0.579	0.425	0.432	16.2	78
2	Wet Pine Brand B	1400	800	500	0.524	0.374	0.394	14.1	87
3	Dry Pine Brand B	1160	560	300	0.707	0.520	0.467	13.2	95
4	Dry Pine Standard Brand	1240	655	380	0.406	0.515	0.442	13.0	78
5	Dry Pine Log	1790	1000	625	0.128	0.084	0.088	17.7	21
6	Wet Oak Standard Brand	3810	1875	1065	0.138	0.108	0.100	25.6	33
7	Wet Oak Brand B	3940	1440	810	0.081	0.101	0.100	21.3	26
8	Wet Hickory Brand B	4600	1530	900	0.083	0.147	0.084	20.2	34
9	Wet Hickory Standard Brand	4220	1630	980	0.087	0.103	0.117	22.3	29
10	Dry Oak Standard Brand	3340	1280	690	0.251	0.224	0.152	15.7	78
11	Dry Hickory Standard Brand	2160	930	510	0.590	0.378	0.454	18.3	102
12	Dry Oak Brand B	2000	970	625	0.312	0.368	0.356	12.1	99
13	Dry Hickory Brand B	2100	990	590	0.453	0.515	0.450	12.2	142
14	Wet Pine Log	4300	2230	2780	0.012	0.002	0.040	17.0	10
15	Wet Hickory Log	4530	2190	2250	0.044	0.228	0.050	15.8	51
16	Wet Oak Log	4600	2470	2125	0.027	0.033	0.004	14.4	14
17	Dry Hickory Log	2600	2500	1380	0.208	0.195	0.243	8.3	164
18	Dry Oak Log	3010	1490	1250	0.213	0.438	0.344	11.7	147

Table 4.5 Summary of Test Data

Number	Fuel	Moisture Content	HHV (BTU/lb)	Efficiency	Test Time (Min)	Cooling Water Temperature (°F)	Average Heat Released (BTU/hr)	Average Heat Output (BTU/hr)	Damper Setting (Position)	Ambient Temperature (°F)	Fuel Consumed (lb)	Average Flue Gas Temperature (°F) Leaving Chimney	Creosote Number
1	Wet pine Standard Brand	8.3%	-8089	55.0%	150	51	52415	28850	1	69	16.2	101	78
2	Wet pine Brand B	8.3%	-8089	55.2%	98	51	63828	38540	1	70	14.1	112	87
3	Dry pine Brand B	0.0%	-8821	43.0%	90	59	77625	33411	1	75	13.2	117	95
4	Dry pine Standard Brand	0.0%	-8821	38.3%	95	59	72425	27761	1	56	13.0	120	79
5	Dry pine Log	0.0%	-8821	58.7%	180	60	52044	30556	2	83	17.7	123	21
6	Wet oak Standard Brand	28.0%	-6351	44.9%	215	61	45374	20366	1	71	25.6	105	33
7	Wet oak Brand B	28.0%	-6351	39.7%	180	61	45093	17909	1	79	21.3	93	25
8	Wet hickory Brand B	27.0%	-6439	42.7%	205	61	38071	16244	1	79	20.2	107	34
9	Wet hickory Standard Brand	27.0%	-6439	41.3%	190	62	45346	18725	1	77	22.3	112	29
10	Dry oak Standard Brand	0.0%	-8821	43.0%	195	63	42612	18329	1	70	15.7	115	78
11	Dry hickory Standard Brand	0.0%	-8821	32.1%	120	64	80712	25892	1	73	18.3	109	102
12	Dry oak Standard Brand	0.0%	-8821	42.4%	90	63	71156	30173	1	71	12.1	110	99
13	Dry hickory Brand B	0.0%	-8821	31.9%	85	62	75964	24207	1	76	12.2	112	142
14	Wet pine Log	42.0%	-5116	51.1%	175	66	29820	15224	2	83	17.0	119	10
15	Wet hickory Log	25.0%	-6615	45.8%	175	66	39198	17965	2	87	15.3	113	51
16	Wet oak Log	26.0%	-6528	37.8%	160	67	35249	13313	2	84	14.4	101	14
17	Dry hickory Log	0.0%	-8821	34.5%	105	67	41837	14414	2	81	8.3	95	164
18	Dry oak Log	0.0%	-8821	40.1%	100	68	61923	24818	2	86	11.7	92	147

Table 4.6 Summary of Test Data [11]

Number	Fuel	Moisture Content (%)	Amount of Pure Creosote
1	Pine; Standard Brand	8.3	2
2	Pine; Brand B	8.3	2
3	Pine; Brand B	0.0	3
4	Pine; Standard Brand	0.0	3
5	Pine; Log	0.0	1*
6	Oak; Standard Brand	28.0	0*
7	Oak; Brand B	28.0	0*
8	Hickory; Brand B	27.0	0*
9	Hickory; Standard Brand	27.0	0*
10	Oak; Standard Brand	0.0	3
11	Hickory; Standard Brand	0.0	4
12	Oak; Brand B	0.0	4
13	Hickory; Brand B	0.0	4
14	Pine; Log	42.0	0*
15	Hickory; Log	25.0	1
16	Oak; Log	26.0	0*
17	Hickory; Log	0.0	4
18	Oak; Log	0.0	4

*Amount of pure creosote is measured on a scale of 0-4. Zero signifies essentially no pure creosote. 4 signifies maximum amount of pure creosote.

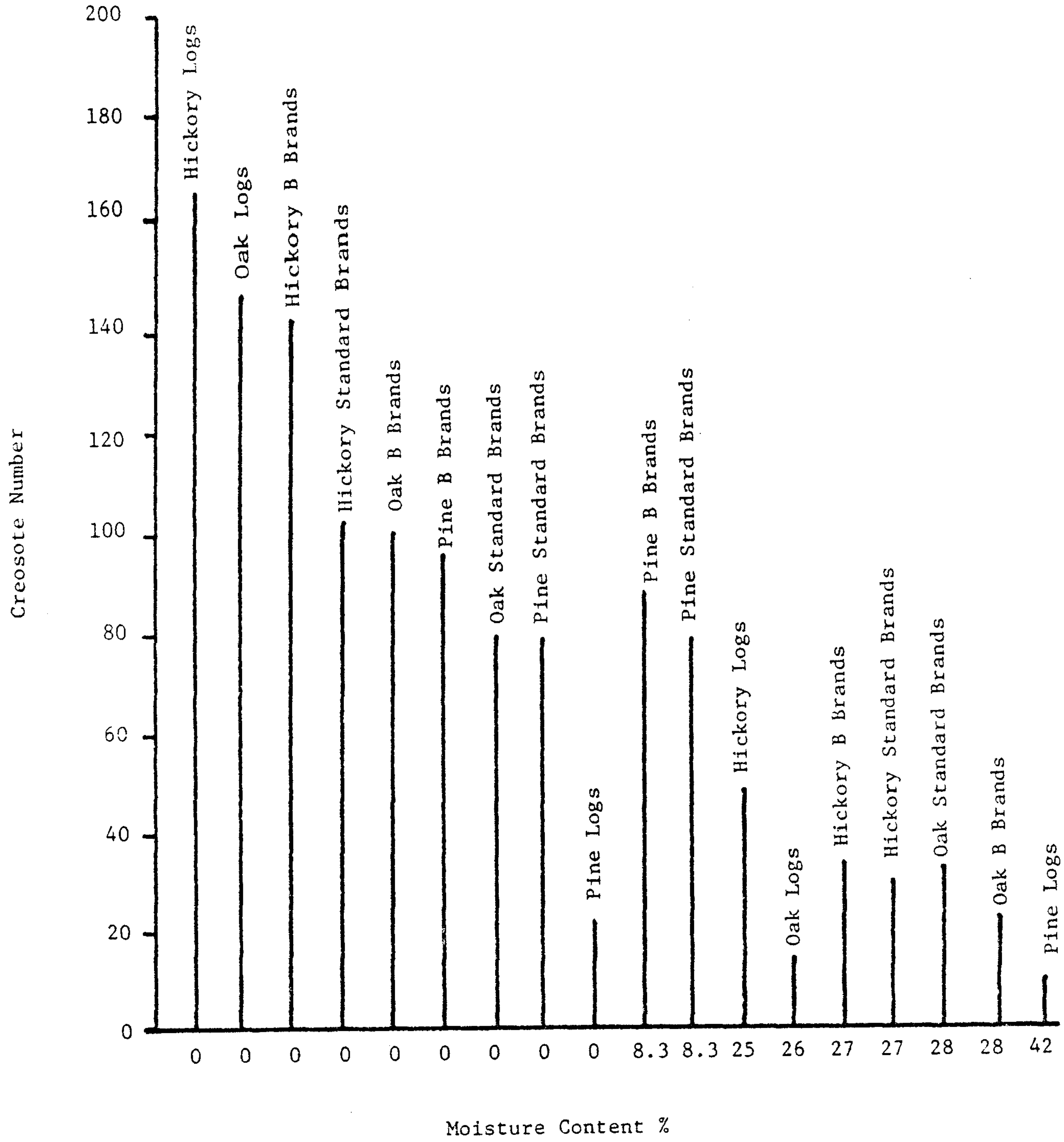


Figure 4.10 Effect of Moisture Content of Wood

effect may occur throughout a significant portion of the burning of a charge of wood.

Effect of Geometry of Wood

Wood geometry is a factor that affects the amount of creosote formed. Three different wood geometries were investigated in the test program. The difference in amount of creosote formed due to wood geometry was difficult to discern for wet woods because of the abundance of water in the creosote/water solution. However, when burning dry wood, the amount of creosote formed was significantly different for the three wood geometries used. Figure 4.11 shows that split logs generated more creosote than the brands under the same test conditions. Type B brands generated more creosote than the standard brands.

It was observed that an abundance of unburned gases and volatile matters were collected in the chimney during the first forty minutes of the test. The reason for this incomplete combustion is directly related to the burning rate. As the burning rate is decreased, the efficiency increases [4]. Thus, as either the surface area of wood becomes larger, or the spacing between the wood pieces that make up the brands becomes narrower, the stove's efficiency improves under the conditions of these tests. Both the Type B brands and standard brands have a large surface area (the standard brands have 610 square inches, Type B brands have 414 square inches), but the standard brands have smaller spacing between the wood pieces. When small wood pieces are spaced close together, not enough oxygen can get in between the closely spaced pieces to burn the gases as fast as they are produced. Thus, a significant portion of the gases is burned well above the solid wood, such that the flame does not heat the wood as much as if the

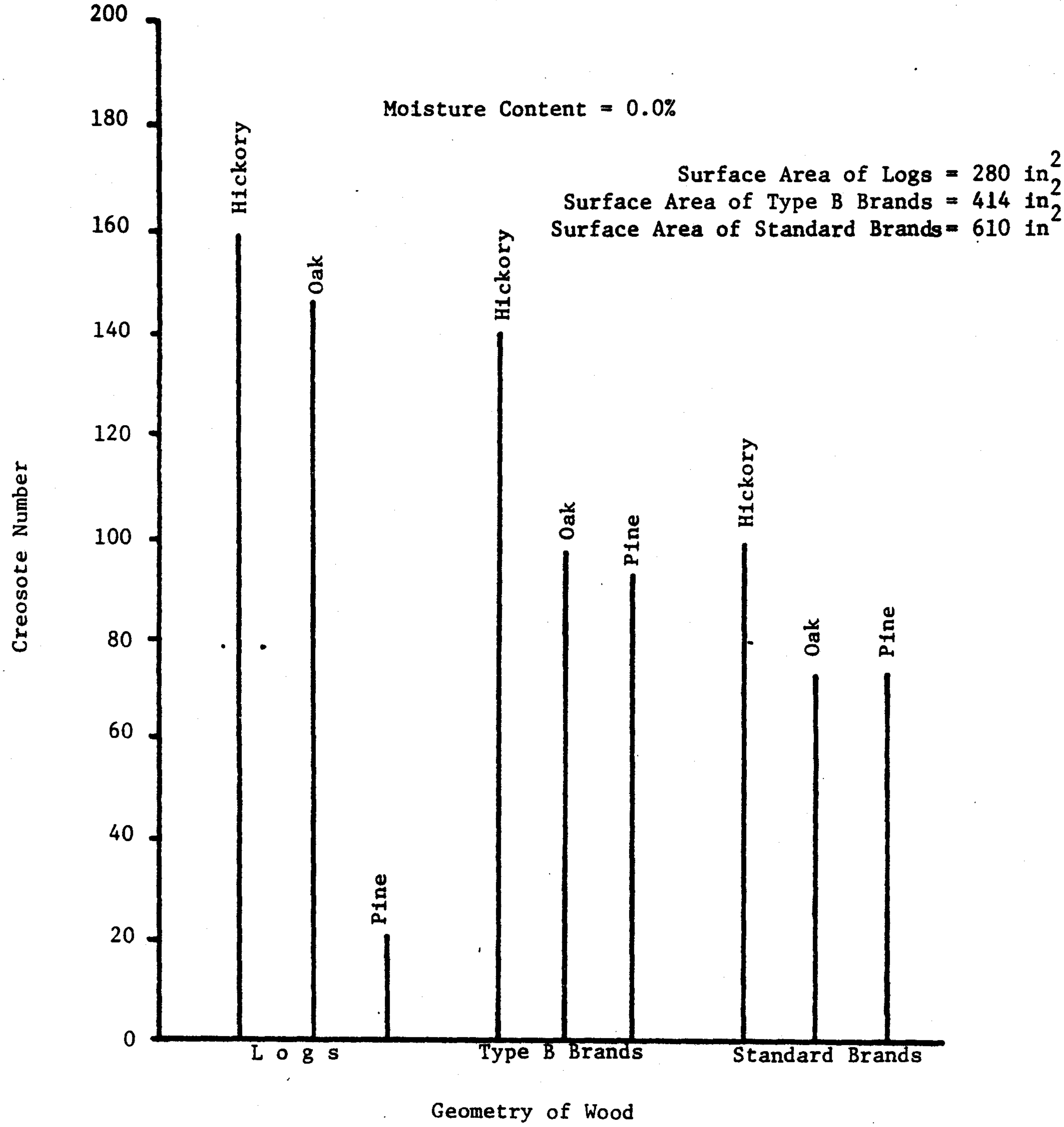


Figure 4.11 Effect of Geometry of Wood

combustion process occurred between the wood pieces. Wood pyrolyzes at a rate which is dependent on the wood temperature.

In order to ignite the split logs (surface area of 280 square inches), a hot bed of coals and larger amount of air were needed in the tests. These special conditions increased the burning rate and resulted in a high production of CO and combustibles during the early period of a test. Thus, large amounts of unburned combustibles were lost up the flue yielding a low efficiency. Creosote deposition occurred when the chimney wall temperatures dropped below about 300°F.

Effect of Type of Wood

No wood type tested prevented the generation of creosote. The hardwoods generated more creosote than the softwood (see Figure 4.12). Undoubtedly, different species of wood have slightly different compositions [11]. Hardwoods have a larger relative density (specific gravity) than do the softwoods; hence, they burned longer. Of the three types of wood that were tested, the hickory generated more creosote than the oak which generated more creosote than the yellow pine.

4.2.1.5. Conclusions

The following conclusions were obtained:

(1) The wood moisture content was the most important factor affecting the amount of creosote produced during these tests; however, in a manner opposite to common beliefs. Dry wood produced more creosote than did wet wood under the same test conditions.

(2) Wood geometry did affect the amount of creosote formed. In burning dry brands, smaller spacing between the wood pieces, or larger wood surface area resulted in less creosote being formed. Split logs produced more creosote than did either type of brands. Geometry of the wood had no observable effect on the amount of creosote formed in burning the wet wood.

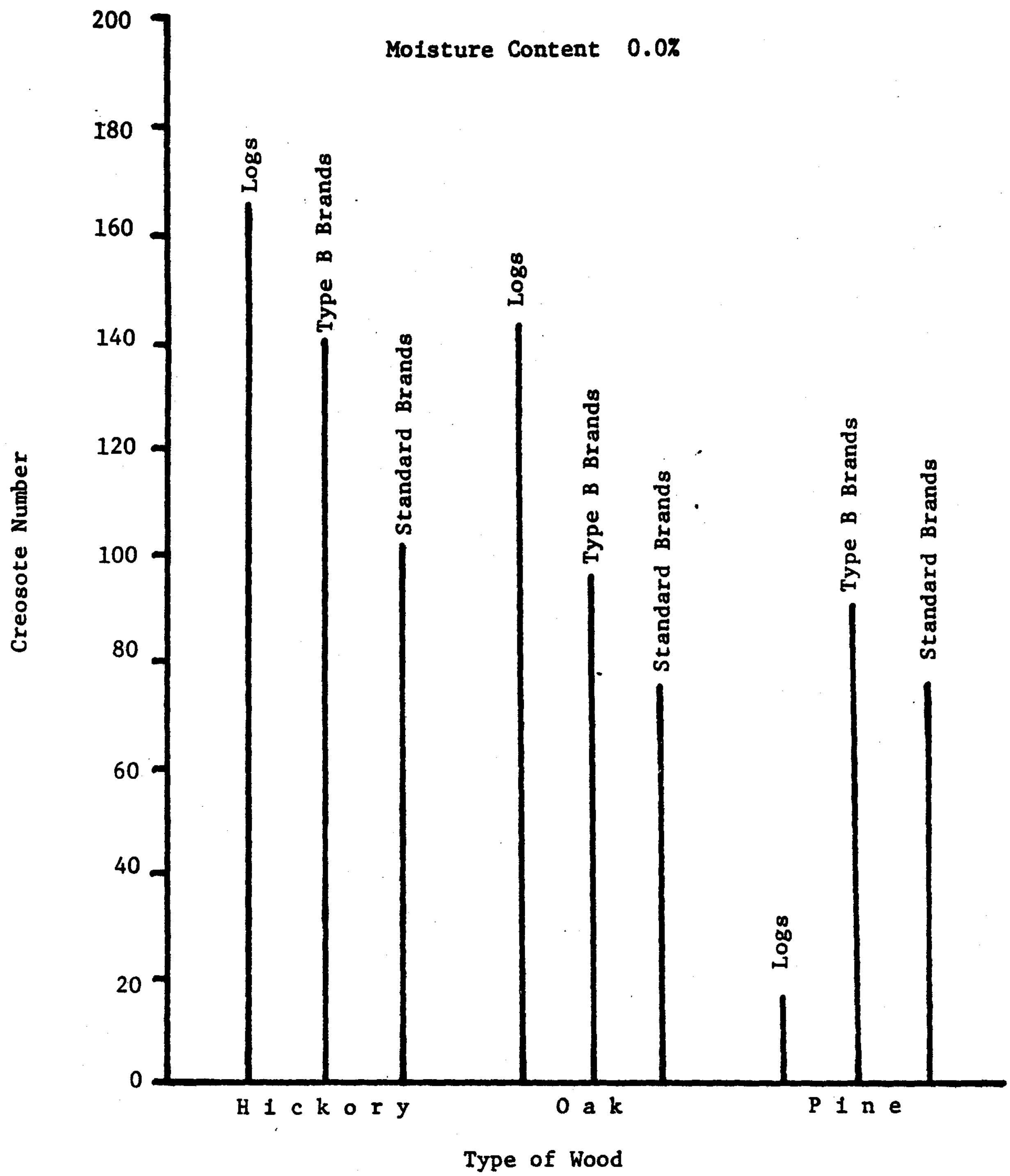


Figure 4.12 Effect of Type of Wood

(3) The wood type affected the formation of creosote. The hardwoods produced more creosote than the softwoods. The relevant factors appeared to be the composition and the relative density of the wood. The higher the relative density of the wood, the larger the amount of creosote produced.

(4) It was observed from this study that small sized semi-seasoned (25-35% moisture content) softwoods produced the least amount of creosote of any of the fuel tested.

Perhaps the most important conclusion is that while the wood type, wood moisture content, and wood piece size do affect the amount of creosote formed, significant amounts of creosote were formed with all the fuels tested. This indicates that there is no "safe" wood that does not produce creosote. Further, it emphasizes the necessity of routine chimney maintenance on the part of home owners who heat with wood. Maintenance should include frequent visual inspections to determine the amount of creosote build-up and periodic chimney cleanings when needed to remove excess creosote.

It should also be recalled that creosote is produced in the combustion chamber of an appliance because of incomplete combustion and then collected in the chimney by a condensation process. Thus, the data presented above relate to the creosote production potential of the stove/fuel/air setting arrangements tested and not necessarily to the amount of creosote that would actually be collected in a home installation.

4.2.2 Second Creosote Study

A second set of tests were conducted to more fully substantiate the results obtained from the first tests and to explore a wider range of parameters. The test chimney described previously was used in the second test series. The only differences in the test procedures used were with respect to the data analysis. The creosote samples were diluted with six parts methanol to one part creosote sample rather than with nine parts water to one part creosote sample as in the first test series. This change was made because the methanol is a better solvent for creosote than is water. The definition for Creosote Number probably changed as a result of the procedure changes. It is expected that the new procedure gives better relative comparisons of the amounts of creosote formed.

4.2.2.1. Test Conditions

Four stoves were used in this test series. The first was a typical circulator unit with a bimetallic strip controller on the air inlet. This type stove has a reputation of being a heavy creosote generator. Two radiant, plate steel units were tested. These units had manually controlled air inlets. Finally a non-airtight Franklin stove was included.

Two type of wood were used in the tests, yellow pine and white oak. Yellow pine is a softwood with a relative density of approximately 29 pounds per cubic foot on a dry basis, and white oak is a hardwood with a relative density of about 41 pounds per cubic foot on a dry basis [8]. The moisture levels of the woods used in this study are listed in Table 4.7.

4.2.2.2. Results

Results of the spectrophotometer analysis are presented in Table 4.8. The results of the tests compare the effects of variations in the wood species and the moisture level for each of the four stoves tested. A summary of the test data is given in Table 4.9, and Figure 4.13 presents the results graphically.

Effect of the Species of Wood

Neither of the two woods tested prevented the formation of creosote. The hardwood, white oak, produced more creosote than the softwood, yellow pine (Figure 4.13 and Table 4.9). Apparently, the density of the wood affects the completeness of combustion, and hence, the creosote formation. The

Table 4.7 Moisture Levels of Test Woods.

Test Number	Wood	Moisture Level	Type Stove
1	Pine	Wet	Radiant "A"*
2	Oak	Wet	Radiant "A"
3	Pine	Dry	Radiant "A"
4	Oak	Dry	Radiant "A"
5	Pine	Wet	Circulator**
6	Oak	Wet	Circulator
7	Pine	Dry	Circulator
8	Oak	Dry	Circulator
9	Pine	Wet	Radiant "B"*
10	Oak	Wet	Radiant "B"
11	Pine	Dry	Radiant "B"
12	Oak	Dry	Radiant "B"
13	Pine	Wet	Franklin***
14	Oak	Wet	Franklin
15	Pine	Dry	Franklin
16	Oak	Dry	Franklin

*Radiant "A" and Radiant "B" were both air-controlled radiant stoves of similar design. Both had manual air inlet controls.

**The circulator stove was a typical circulator with a bi-metallic strip combustion air inlet controller.

***Franklin type of stove of non "air-tight" construction

Table 4.8 Results of Spectrophotometer Analysis

Test Number	Fuel	Volume of Mixture (ml) 1-sec	2-sec	3-sec	Optical Density (450 nm) 1-sec	2-sec	3-sec	Wood Consumed	Creosote Number
1	Wet Pine	503	598	0	.254	.157	0	9.80	22.6
2	Wet Oak	393	387	0	.353	.267	0	6.5	37.2
3	Dry Pine	273	501	0	.170	.117	0	9.90	10.6
4	Dry Oak	253	376	0	.378	.219	0	7.95	22.4
5	Wet Pine	903	709	2	.398	.289	4.02	10.5	54.5
6	Wet Oak	570	555	503	.466	.363	.690	10.55	77.2
7	Dry Pine	351	544	3	.405	.268	1.735	11.45	26.5
8	Dry Oak	598	742	519	.284	.256	.438	11.40	51.5
9	Wet Pine	247	627	0	.108	.083	0	8.00	9.7
10	Wet Oak	622	501	1	.232	.163	1.672	5.95	38.3
11	Dry Pine	403	610	35	.133	.108	.406	8.45	15.8
12	Dry Oak	395	719	0	.134	.190	0	8.85	21.4
13	Wet Pine	155	394	0	.098	.120	0	8.85	7.1
14	Wet Oak	114	372	329	.173	.218	.211	9.05	18.8
15	Dry Pine	158	373	17	.116	.111	.662	9.35	7.6
16	Dry Oak	190	445	398	.109	.075	.137	9.45	11.5

Table 4.9 Summary of Test Data

Test Number	Fuel	Test Time (min)	Ambient Temperature (^oF)	Fuel Consumed (lbs)	Temperature (^oF) (T_7)	Creosote Number
1	Wet pine	95	60	9.8	249	22.6
2	Wet oak	65	60	6.5	210	37.2
3	Dry pine	75	68	9.8	295	10.6
4	Dry oak	90	58	7.95	226	22.4
5	Wet pine	120	62	10.5	178	54.5
6	Wet oak	110	63	10.55	131	77.2
7	Dry pine	75	60	11.0	244	26.5
8	Dry oak	85	69	11.4	135	51.5
9	Wet pine	90	63	8.0	194	9.7
10	Wet oak	80	73	5.95	150	38.3
11	Dry pine	90	72	8.45	179	15.8
12	Dry oak	90	70	8.85	186	21.4
13	Wet pine	80	72	8.85	172	7.1
14	Wet oak	95	69	9.05	96	18.8
15	Dry pine	60	59	9.35	188	7.6
16	Dry oak	70	72	9.45	118	11.5

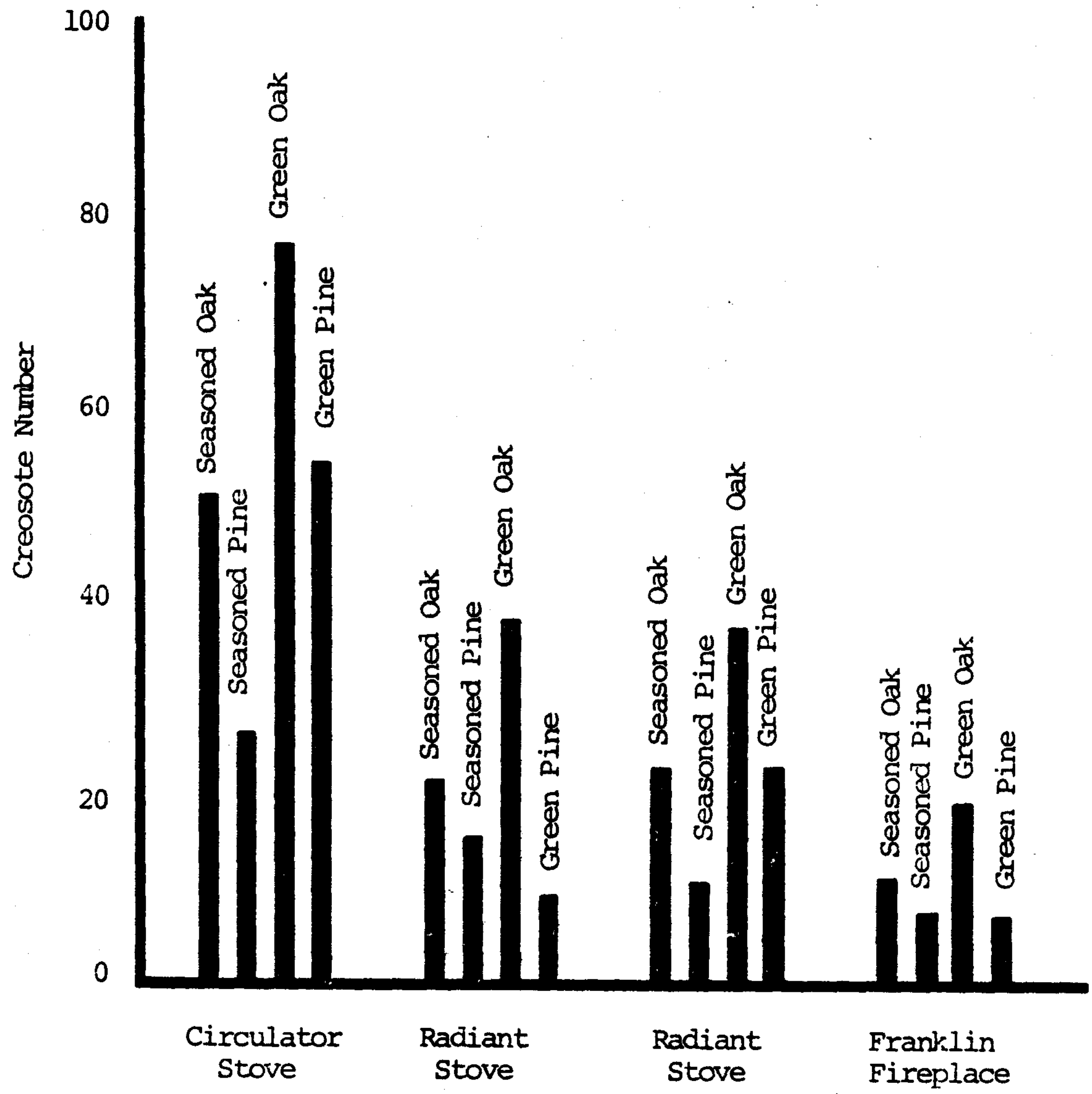


Figure 4.13 Creosote Numbers for Different Type Appliances

lighter wood is heated to pyrolization temperature more quickly and more evenly; thus, combustible gases are emitted more rapidly, especially early in the burning of each piece of wood.

Effect of Moisture Level

No moisture level tested prevented the generation of creosote. The wet wood produced more creosote than the dry wood. This result is the opposite of other tests conducted [8, 6]. The tests conducted in [8] and [6] were performed under a low burn rate. The tests in this study were performed under a high burn rate. Reference [6] also concluded that wet wood produced more creosote than dry wood under a high burn rate. The moisture level does effect the amount of creosote produced, but the rate at which wood is burned is also a factor. Thus, the moisture level and the air inlet setting are interrelated in the formation of creosote.

4.2.2.3. Conclusions

Based on these tests, the following conclusions are made:

(1) The species of wood did have an effect on the generation of creosote. The hardwood produced more creosote than the softwood. The relative densities appear to be a factor in creosote formation.

(2) The moisture level also had an effect on the amount of creosote produced. Wet wood produced more creosote than dry wood at high burn rates. Other studies indicate opposite trends at low burn rates. This implies that the water in the wood may increase or decrease the amount of creosote produced, depending on the firing rate.

(3) The type of stove made, by far, the largest effect on the amount of creosote produced. This is due to the different amounts of air available for combustion in the different units and to the different mixing processes within the combustion chambers of each unit. Hence, the burning conditions or mode of operation is the most significant factor in creosote formation.

A major point should be noted; while each of these parameters did affect the amount of creosote formed, there are many other parameters that should be considered. Much more research must be carried out to evaluate their effect.

4.2.3. Pine Beetle Infested Wood Study

Between 1979 and 1980 southern pine beetles, the major insect killer of southern pines, destroyed approximately 856,000 cords of pine timber. Forest industries salvaged 64 percent of the infested timber [4]. The 36 percent not salvaged could be used as a source of energy for homes that have wood burning appliances. Due to the increasing demand for wood for fuel, this extensive source of fuel wood can not be overlooked.

Tests run at the Auburn Wood Burning Laboratory, described above, showed that the type and moisture content of the wood burned do affect creosote formation to a small degree, but generally not in the manner traditionally thought. However, all of the tests conducted at AWL were laboratory tests that were not intended to reproduce exactly conditions of a stove in a home. Thus a study was undertaken by the Georgia Forestry Commission in conjunction with the Auburn Wood Burning Laboratory Personnel to compare the creosote production characteristics of pine and other woods under conditions more representative of a typical stove installation. In particular, the objectives were:

(1) to determine if beetle killed pine can be burned in wood burning stoves without excessive creosote production

(2) to determine how the creosote production from beetle killed pine compares with the creosote production of other wood species at various moisture contents.

4.2.3.1. Test Set-Up and Procedure

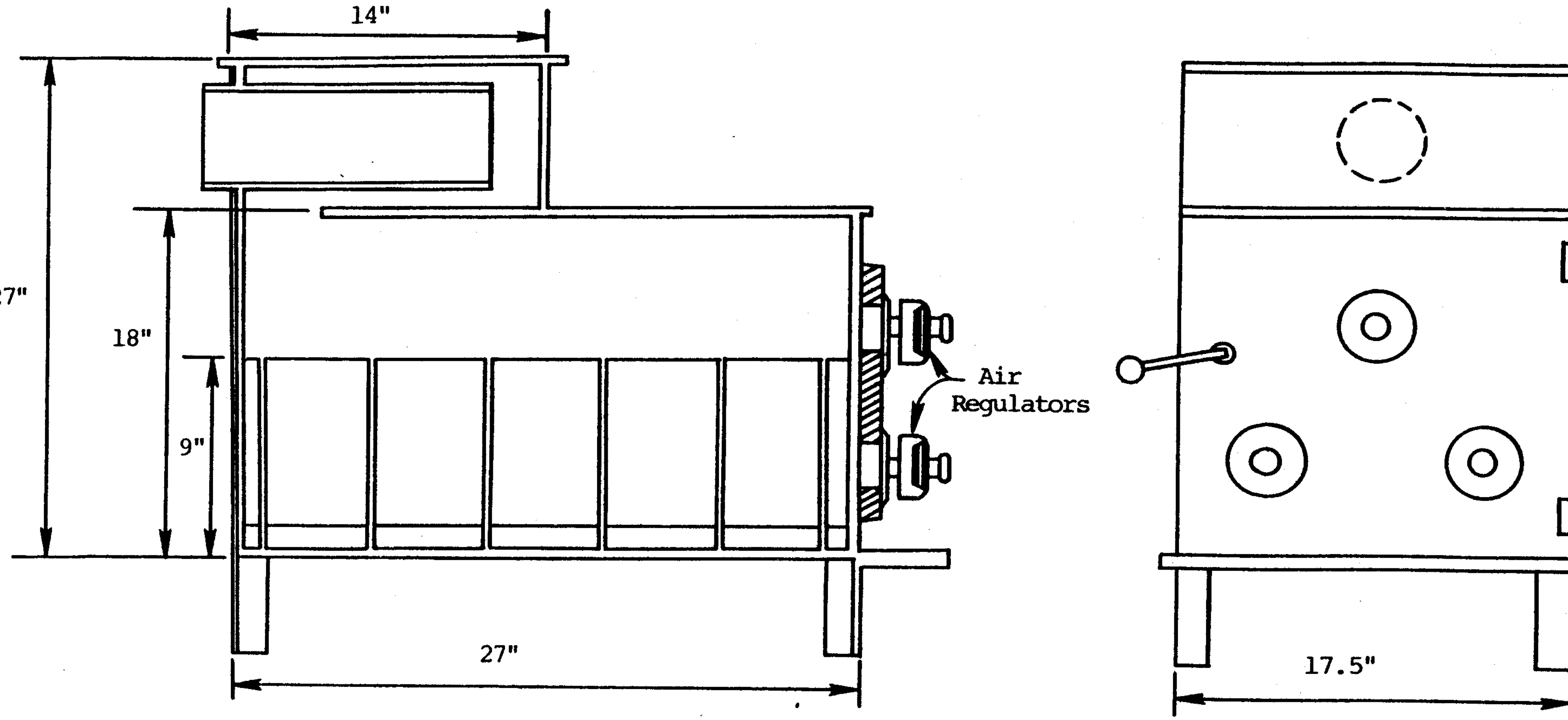
The test program consisted of operating four wood burning stoves for approximately one month. Periodically, the mass of creosote deposits in the chimney of each stove was measured. A different type wood was used to fire each stove; hence, the relative amounts of creosote deposit produced by each type wood could be determined.

The stoves were radiant units made of plate steel in a typical two step design. Figure 4.14 shows a schematic diagram of the type stove used. The four stoves were supplied by the same manufacturer and were essentially identical. The stove pipe connections consisted of an adapter, a 90^{o} elbow, and three 24 inch long sections of 6 inch diameter, 24 gauge stove pipe. The stove pipe was joined to a prefabricated chimney that included a roof support section, two 30 inch long sections, and a chimney cap. The prefabricated chimney was a typical insulated type chimney (two stainless steel walls with 1 inch of solid packed insulation between). Figure 4.15 shows a schematic diagram of the stove and chimney arrangement. The four units were located in a row approximately 6 feet apart.

The stoves were operated at a very low air inlet setting to typify home operation. A thermometer was installed midway up the first section of single wall stove pipe. The air inlets on each stove were adjusted as required to maintain a flue gas temperature between 300-350^{o}F.

The stoves were charged with wood as needed to maintain the desired flue gas temperature as described above. Generally, this required chargings in the morning and afternoon. All of the stoves were fully charged at the end of each working day and allowed to burn overnight.

Each time a stove was charged, the mass of wood input, the time, and the ambient temperature were recorded. Before installation each section of stove pipe and chimney was weighed and recorded. After ten days of operation, the stove pipe and chimney sections were carefully disassembled and reweighed. To prevent loss of creosote, the sections were tapped lightly so that the very loose creosote deposits were removed. The sections were again reweighed and then reassembled on the stoves from which they came. After twenty days of operation, the weighing procedure was repeated. This



Side View

Front View

Figure 4.14 Schematic Diagram of Stove Used in Test

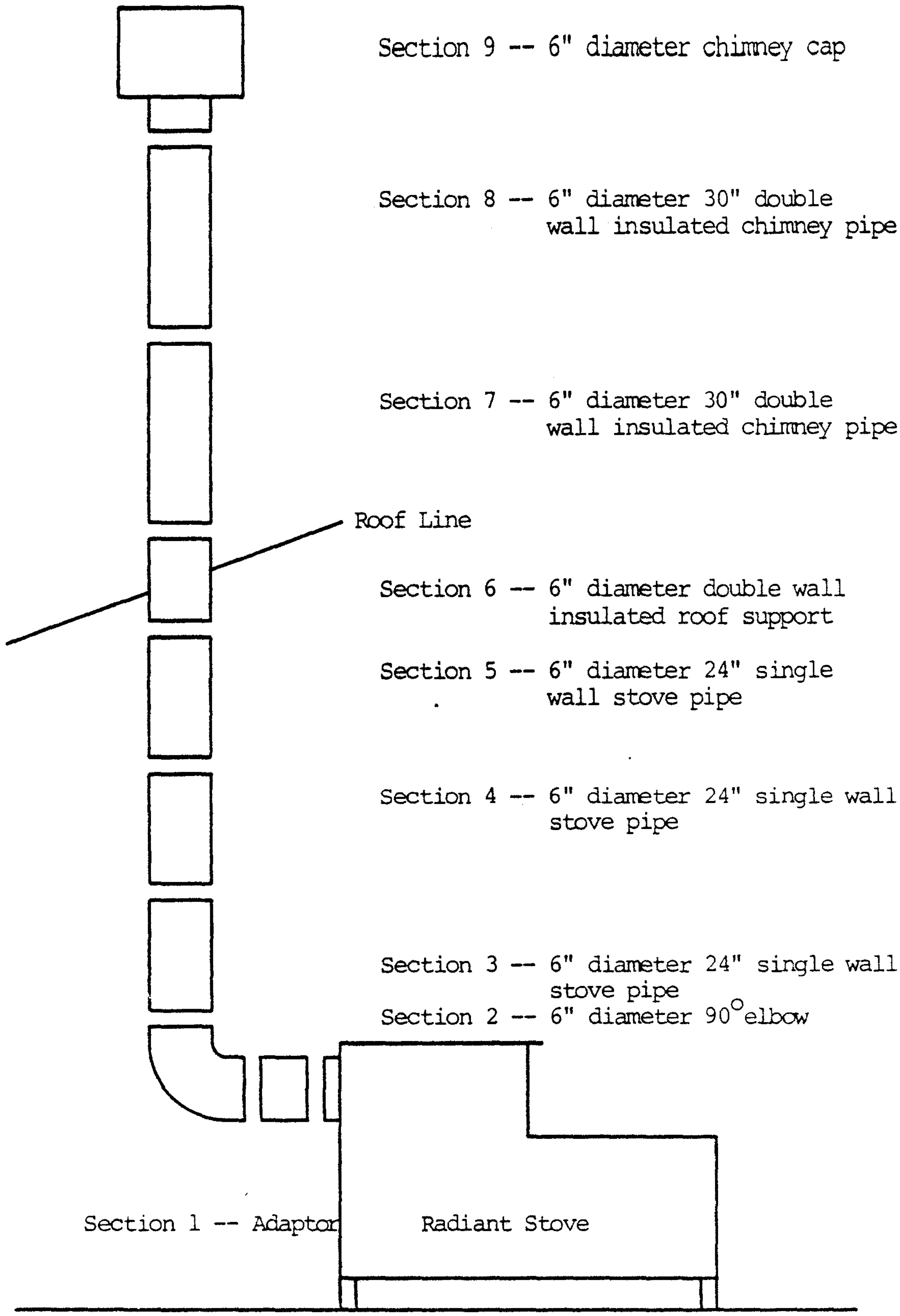


Figure 4.15 Stove-Chimney Set Up

time the chimneys were reassembled on different stoves. Finally, after thirty-three days of operation, the chimneys were disassembled, and a last weighing was carried out.

Two stoves were fired with mixed hardwoods (oak and hickory), one burning seasoned hardwood, the other green hardwood. The other two stoves were fired with beetle-killed pine and green pine respectively. All of the wood was in the form of split and round pieces. Random samples were taken from each wood group at various times during the tests and the moisture content was measured.

4.2.3.2. Results

All wood moisture contents were determined on a wet basis. The beetle-killed pine, samples from trees that had been dead approximately ten months as a result of beetle infestation, had an average moisture content of 24 percent. The green pine was the wettest wood tested; it had an average moisture content of 46 percent. The seasoned hardwood had been stored outside for approximately 1 and 1/2 years. It had the lowest moisture content, 14 percent. The green hardwood samples averaged 30 percent moisture.

Table 4.10 summarizes the test results. A total of 1545 lbm of beetle-killed pine was burned. This produced 3.61 lbm of creosote with a typical tar-like appearance. The green pine, because of its high moisture content, was difficult to start, but once a bed of coals was established, an adequate fire could be maintained. 2096 lbm of green pine were burned during the test, and this produced 1.81 lbm of a powdery textured creosote. The seasoned hardwood produced 3.84 lbm of creosote from 2079 lbm of wood, and 2484 lbm of green hardwood produced 3.22 lbm of creosote. The creosote produced by both the wet and seasoned hardwoods had a typical sticky, tar-like consistency.

Table 4.11 compares the creosote accumulation per unit of wood consumed on a wet basis and a dry basis. Both means of comparison show that the beetle-killed pine produced the largest accumulation of creosote. The beetle-killed pine was followed by the seasoned hardwood in creosote production. The green woods produced lesser amounts of creosote; the green pine produced the smallest amount of any of the test woods.

Figure 4.16 shows the variation of creosote accumulation versus moisture content for the tests run. The drier woods produced more creosote than did the wetter woods. A comparison of the sectional accumulation is shown in Table 4.12. As expected, the creosote accumulation was much greater in the lower, single wall stove pipe sections than in the upper insulated chimney sections. The results of this study generally agree with the studies performed at AWL and at the University of Wisconsin [6].

4.2.3.3. Conclusion

All of the woods tested produced significant amounts of creosote accumulation. The woods with the lower moisture contents produced the largest amounts of creosote accumulation. This agrees with the results reported by others, Maxwell, et. al. [8, 10, 16] and Jorstad [6 and 7].

The beetle-killed wood produced more creosote than did the other woods tested. However, all of the woods produced significant amounts of creosote. Thus, beetle-killed pine should not be rejected as a fuel wood on the basis of creosote production.

Based on the relative creosote production, green pine would be the best choice for fuel wood. However, many parameters should be considered when obtaining fuel wood. On a dry basis there is little difference in

Table 4.10 Summary of Creosote Test Results

Wood Type	Mass of Fuel (Wood and Moisture) Consumed (lbm)	Mass of Creosote Accumulated (lbm)	Average Flue Gas Temperature °F	Average Moisture Content % (Wet Basis)
Beetle-Pine	1545	3.61	317	24.74
Green Pine	2096	1.81	317	46.14
Seasoned Hardwood	2079	3.84	313	13.54
Green Hardwood	2484	3.22	317	30.43

Table 4.11 Creosote Accumulation Per Mass of Wood

Wood Type	Mass of Creosote Accumulated (lbm)	Mass of Fuel (Wood and Moisture) Consumed (lbm)	Mass of Dry Wood Consumed (lbm)	lbm Creosote Ton Fuel	lbm Creosote Ton Dry Wood
Beetle-Pine	3.61	1545	1163	4.67	6.21
Seasoned Hardwood	3.84	2079	1798	3.69	4.27
Green Hardwood	3.72	2484	1728	2.59	3.73
Green Pine	1.81	2096	1129	1.73	3.21

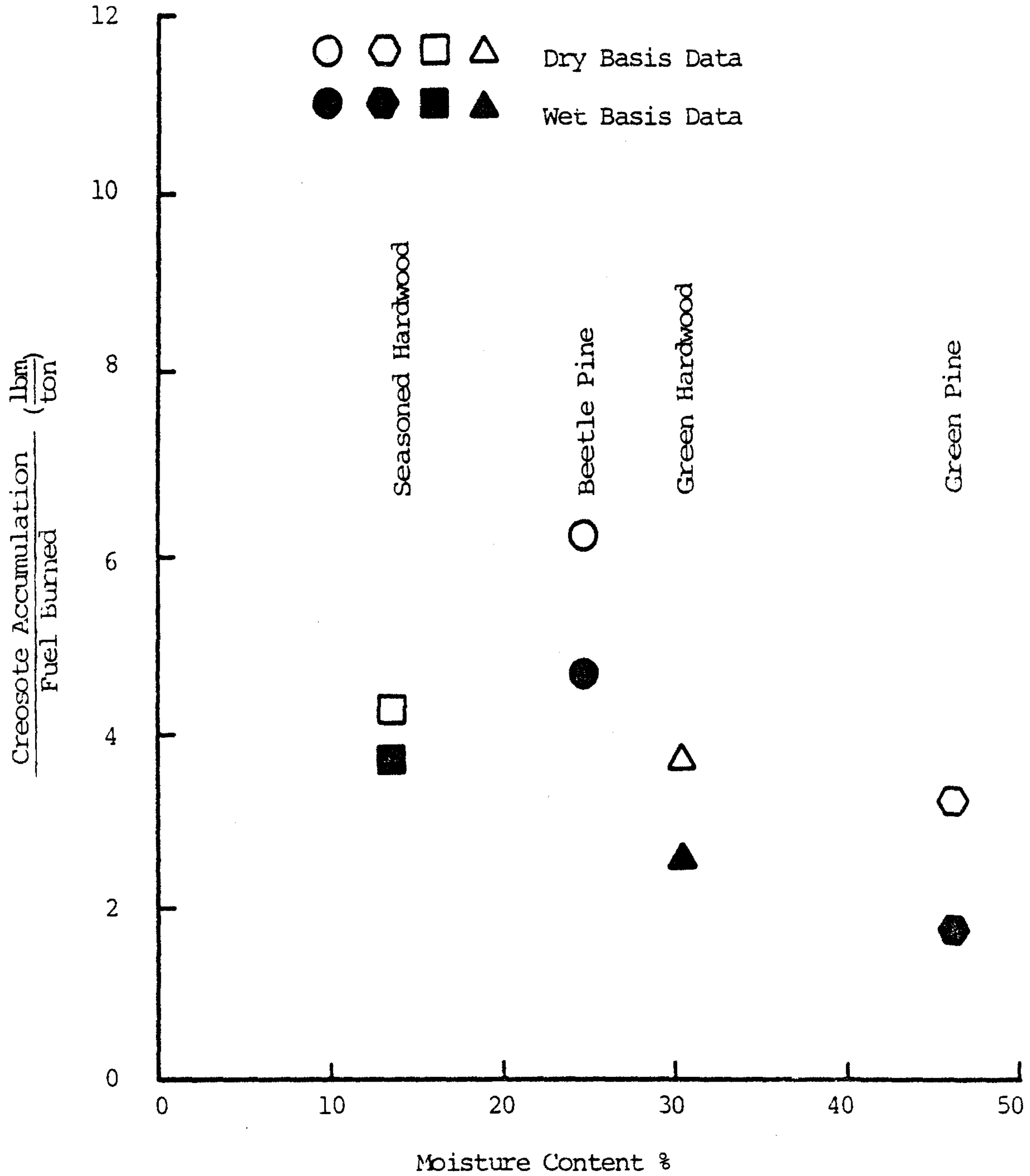


Figure 4.16 Creosote Accumulation vs Moisture Content

Table 4.12 Sectional Comparison of Creosote Accumulation in Stove Pipe and Chimney

Section*	Beetle Pine	Green Pine	Seasoned Hardwood	Green Hardwood	
1	.1063	.0542	.0836	.0591	Adapter
2	.1846	.1409	.1960	.2035	90° Elbow
3	.7369	.3766	.7217	.6066	24 inch sections
4	.7689	.3191	.7385	.6141	of single wall
5	.6659	.3012	.7301	.5978	stove pipe
6	.1535	.0600	.1629	.1314	Double wall roof support
7	.3230	.1268	.4648	.3034	30 inch sections of double wall insulated chimney pipe
8	.2972	.1358	.2944	.2600	
9	.3762	.2911	.4441	.4401	chimney cap

*Section Numbers correspond to Figure 2

Creosote Accumulations in lbm

the energy content per pound of different species of wood; but because pine is much less dense than most hardwoods, the volume of pine required to produce a given amount of heat will be greater than that of oak or hickory. This also means that a full charge of pine will not burn as long as a full charge of hardwood. The two parameters that most likely determine the source of fuel wood a home owner selects are cost and availability. Beetle-killed pine should have an advantage over hardwoods with respect to cost.

All things considered, seasoned hardwoods are probably the best choice for fuel wood. However, as noted earlier, the demand for fuel wood is growing, and thus, the large amount of beetle-killed pine cannot be overlooked. This study and others show creosote accumulation is relatively unaffected by the species and moisture content of the wood burned. In fact, the only real factor is the amount of air provided to the combustion process, the type of appliance and the air inlet settings. Any type wood can be burned without undue creosote accumulation if the appliance is operated with sufficient combustion air.

4.3. Current Creosote Study

4.3.1. Laboratory Tests

Six combinations of fireplaces and inserts were involved in the creosote tests. Table 4.13 lists the tests and combinations. The inserts were set up in the host fireplaces and operated for several days at low air inlet settings so that flue temperatures ran at less than 300°F. The fuel used was partially seasoned split oak; moisture content ranged from about 25% to 45%. Each insert was fired at 8 AM and refueled during the day as needed.

Table 4.13 Creosote Test Runs

Run #	Fireplace	Insert	Day Burned	Mass of Wood Consumed lbm
1	Masonry	No. 1	10	508
2	Masonry	No. 2	10	526
3	Masonry	No. 5	12	385
4	Masonry	No. 5C	6	243
5	F1	No. 4	15	488
6	F2	No. 6	10	403

At 5 PM a charge of fuel was added to the insert and it was then left until the next morning.

None of the tests produced significant levels of creosote buildup, certainly not enough to make any quantitative measurements of the relative creosote buildup between the different tests. This result is not a new experience: other tests intended to compare the creosote buildup in various types of chimneys have to a large degree yielded similar results. During stove tests elbows and horizontal sections of stove pipe have been completely filled with creosote; however it is difficult to collect large amounts of creosote in the vertical sections of a chimney under laboratory conditions. The masonry fireplace was situated completely inside the laboratory. Therefore, it was exposed to ambient temperatures of 70^{O}F or above year round. The tests in the other two fireplaces were conducted out of doors, but during the summer months. Perhaps the relatively high ambient temperatures retarded the creosote buildup. Flue gas analysis indicated that at least some of the inserts were operating at excess air levels that are very high with respect to excess air levels for airtight stoves. Either the inserts were not as "airtight" as airtight stoves or air leaked around the insert and into the chimney as well as passing through the firebox. However, the inserts were installed in the fireplaces as recommended by the manufacturers' instructions and were sealed at least as well as a typical home installation. The high level of excess air could also have lowered the creosote collection rate. If the extra air was entering through the firebox, then indeed, the units were surely operating so that little creosote was being produced. On the other hand if the excess air was leaking around the inserts and mixing in the chimney, then it could well have diluted the flue gases, and hence, prevented the creosote from condensing in the chimney.

The results of these tests should not be construed to mean that inserts do not produce creosote. Rather, for the tests conducted significant levels of creosote were not produced.

4.3.21 Field Tests

Inserts in two homes in the Auburn area were monitored during the 1980-81 heating season. The amount and type of wood burned and the relative creosote buildup were observed. A Type 13 (Table 2.2) insert was installed in each home.

Home #1 was a single story ranch style home of approximately 3000 square feet. The fireplace was located in the family room near the center of the house on an inside wall. The insert provided approximately one half of the heat required by the home. One cord of unseasoned hardwood (mostly oak) was burned during the heating season.

Home #2 was a two story house of approximately 2000 square feet. The fireplace was located downstairs on an outside wall at the rear of the house. The insert was used to heat the entire downstairs. One to one and a quarter cords of hardwood (mostly oak and hickory) were burned during the heating season. Approximately 1/2 of the wood consumed was seasoned and the remainder was green.

Both inserts were operated with the air inlets full open during a large percentage of the time that there was a fire, especially just after fresh charges of wood were added. When the inserts and fireplaces were checked at the end of the tests, no significant creosote was found. Some soot that was already in the chimneys remained but no sticky or hard deposits were found. A small quantity (2 or 3 cups) of gray ash was found partly on the top of the inserts and partly on the floor of the fireplace around the sides of the inserts. This appeared to be ash that had been carried out of the insert during periods of high burn rate and then settled back down on top of the insert. Of course, it is possible that this material was discharged from the insert as soot or creosote, collected on top of the insert and on the inside of the fireplace firechamber, and then was burned at a later time due to a particularly hot fire in the insert. There was no evidence that a chimney fire had occurred.

One very interesting episode occurred with the insert in house #2. One evening approximately one to one and one-half hours after a fire was lit in the insert, a very loud bang was emitted. At first it was assumed that an "explosion" had occurred inside the insert or behind the insert in the fireplace. However, close inspection showed that the loud noise had been produced by the outer shell of the insert (1/8 in sheet metal) warping slightly but suddenly as the insert was heating up to operating temperature. This warping, popping phenomena did not occur every time the unit was fired, but it did occur occasionally. The arrangement of wood, the location of the hottest part of the fire, and the rate of heating all affect the relative thermal expansion of the various components of the insert, thus, the sudden popping, and sometimes the insert would merely expand or contract without sudden changes. It is being suggested that this can account for all "explosions" related to inserts; however, it is likely that this phenomena accounts for many unusual noises and vibrations.

Finally, the insert in home #2 suffered several broken glasses. This insert was equipped with ordinary tempered glass. Usually the breakage occurred just after the doors were opened and wood was added. The insert was equipped with screens in front of the glass panels; hence, no immediate danger resulted. However, the fire began to burn much more rapidly and hotter as a result of the larger supply air suddenly available.

5. Thermal Performance

5.1. General

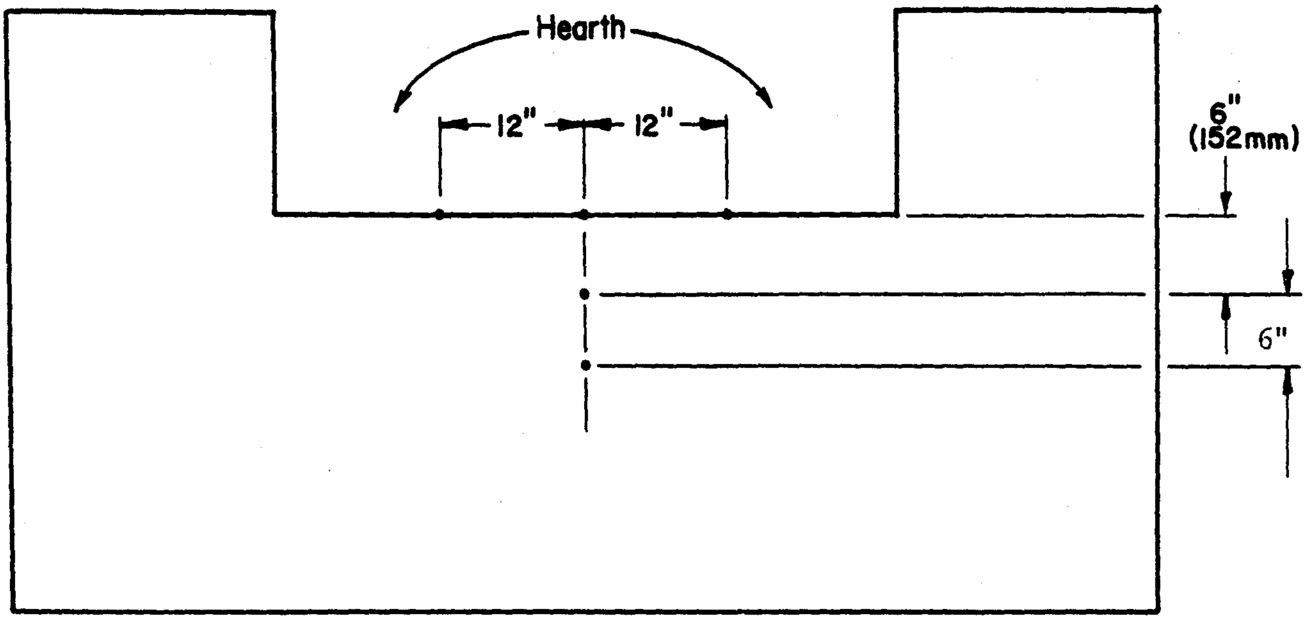
The thermal performance of several insert-fireplace combinations was measured. The units were instrumented with thermocouples and the temperatures at approximately 100 locations were monitored. The locations where temperatures were monitored included points within the fireplace materials, the flue gases and points on a plywood encasement constructed around the fireplace. The primary interest of these tests was to determine the maximum temperature rises produced on combustible materials in or near the fireplace. The general test procedure used is described in proposed Underwriters Laboratories Standard UL 907.

5.2. Test Setup and Test Procedure

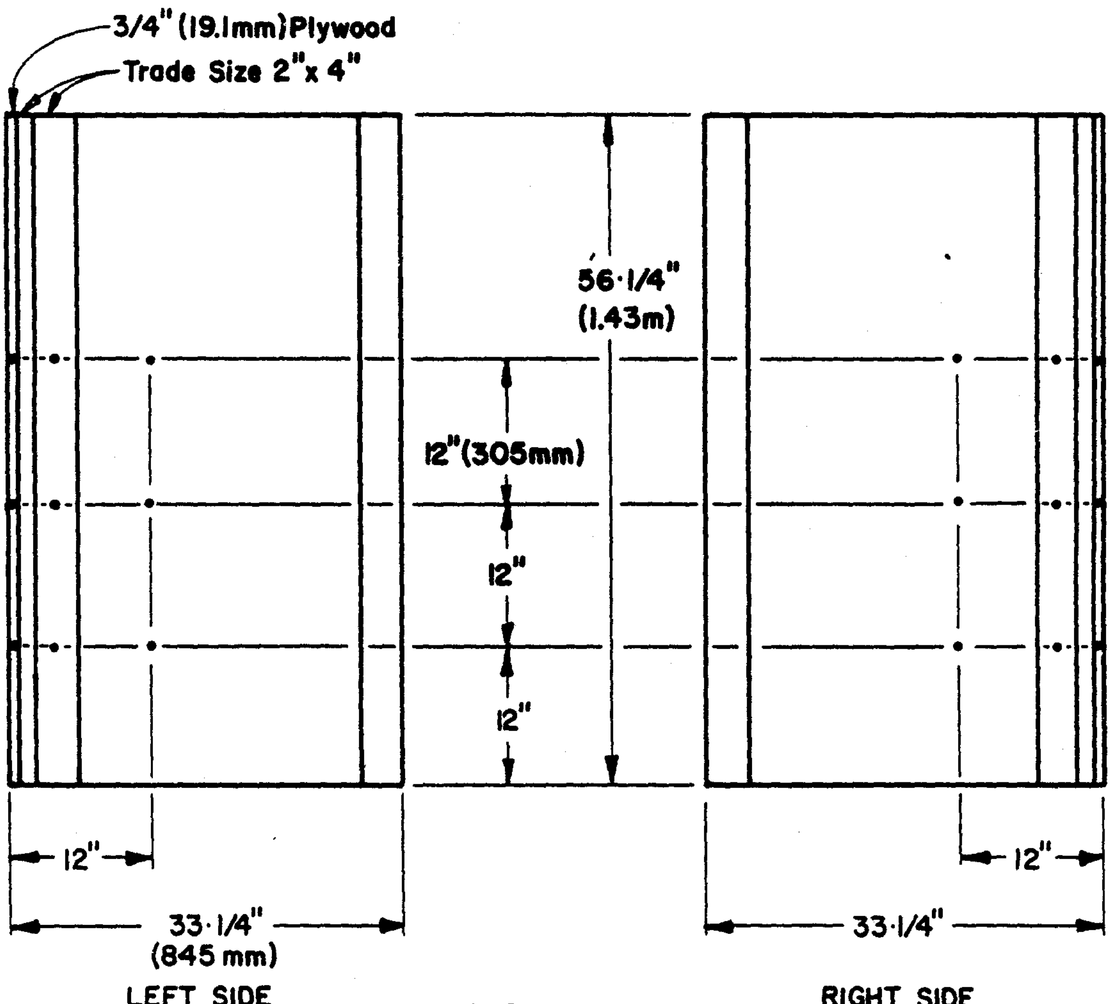
Two fireplaces were used during the testing. The first was a masonry fireplace designed by Underwriters Laboratories personnel to be a minimal unit. That is this fireplace just meets the average codes for masonry fireplaces. Drawings of their unit are included in Appendix B and a complete description is in Reference 14 . The manufactured fireplace used, No. F2, was described in Chapter 3.

The thermocouple locations for the masonry fireplace are shown in Figures 5.1 through 5.7 and are defined briefly in Table 5.1. Figures 5.8 through 5.12 show the thermocouple locations for fireplace F2.

Log fires and brand fires were used in the testing. Brands were made from 3/4 inch by 3/4 inch strips of Douglas fir fastened together in a criss-cross pattern on 1 inch centers. The brands were then dried in an oven at 212°F overnight to ensure uniform dryness. The brands were sized



FLOOR THERMOCOUPLES



Metric Conversions, lumber

Trade Size, Inches	Metric Equivalent mm
2 x 4	44.4 x 95.3

Figure 5.1 Masonry Thermocouple Locations, Fireplace Enclosure

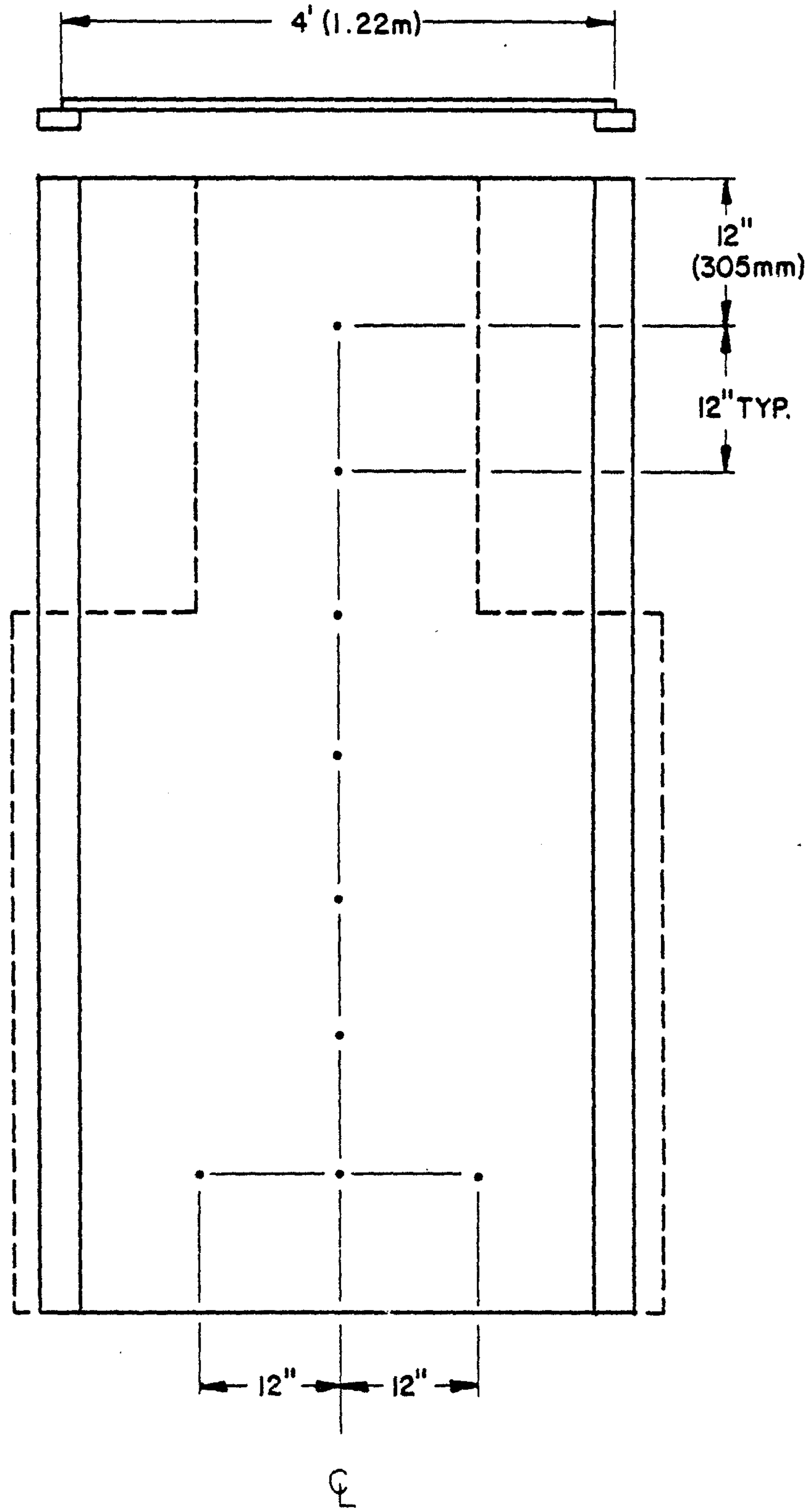
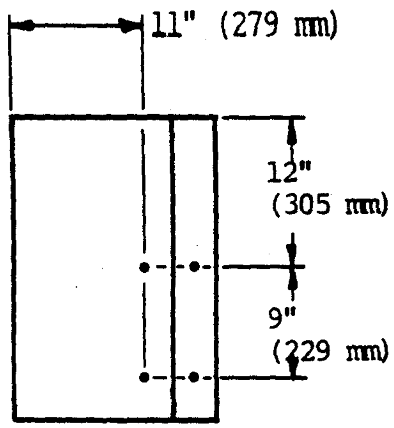
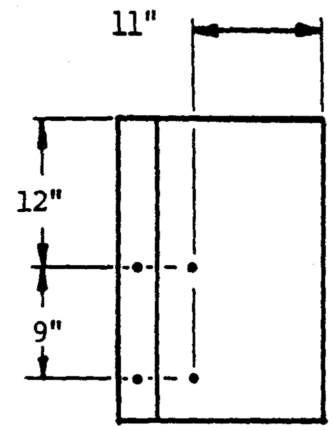


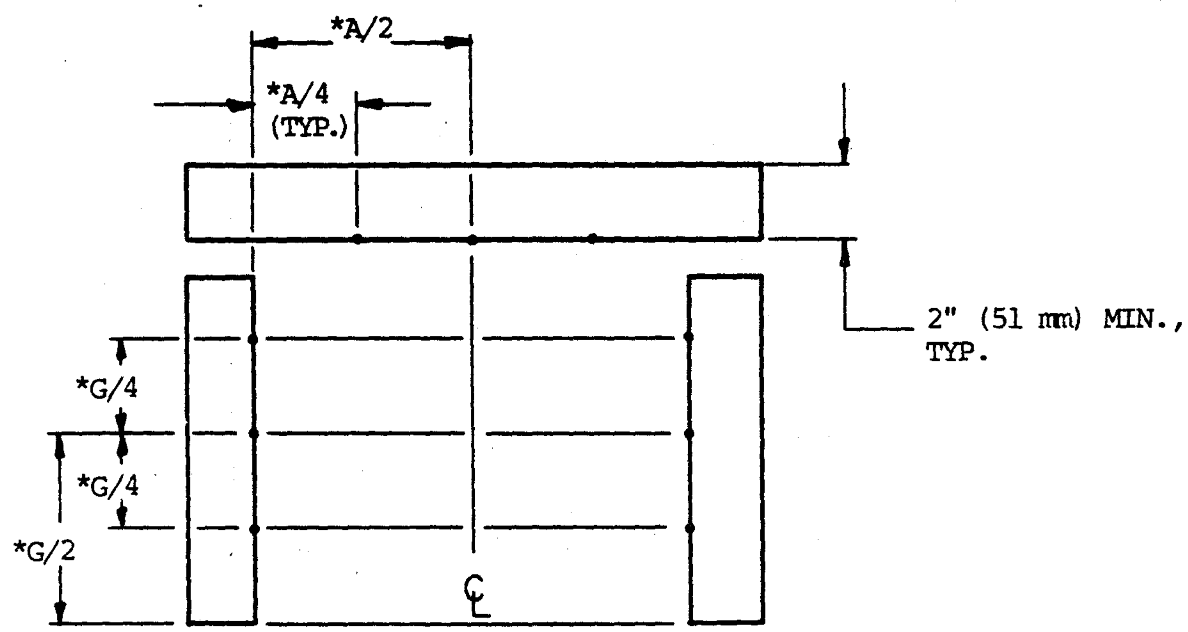
Figure 5.2 Masonry Thermocouple Locations, Back Wall of Enclosure



Top of Firebox, Left Side



Top of Firebox, Right Side



Trim around fireplace opening.

Figure 5.3 Masonry Thermocouple Locations, Top of Firebox and Trim

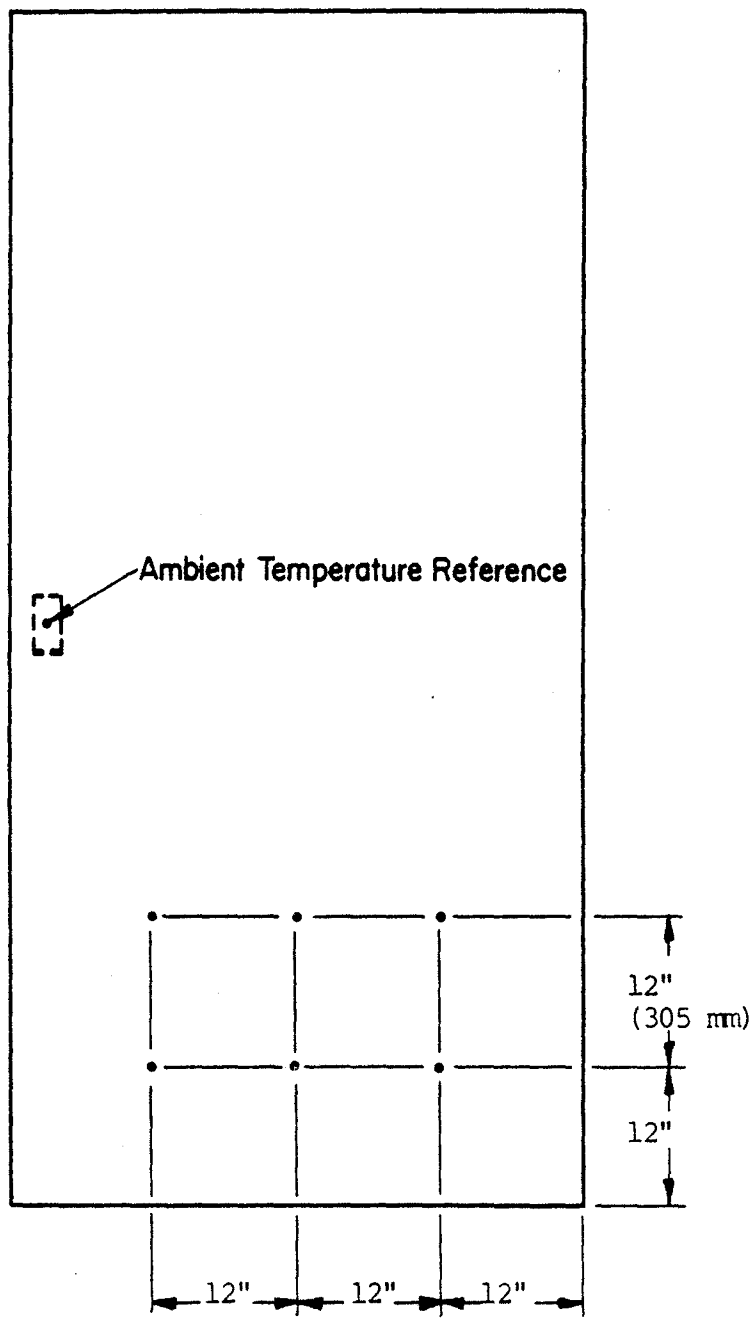


Figure 5.4 Masonry Thermocouple Locations, Left Adjustable Side Wall

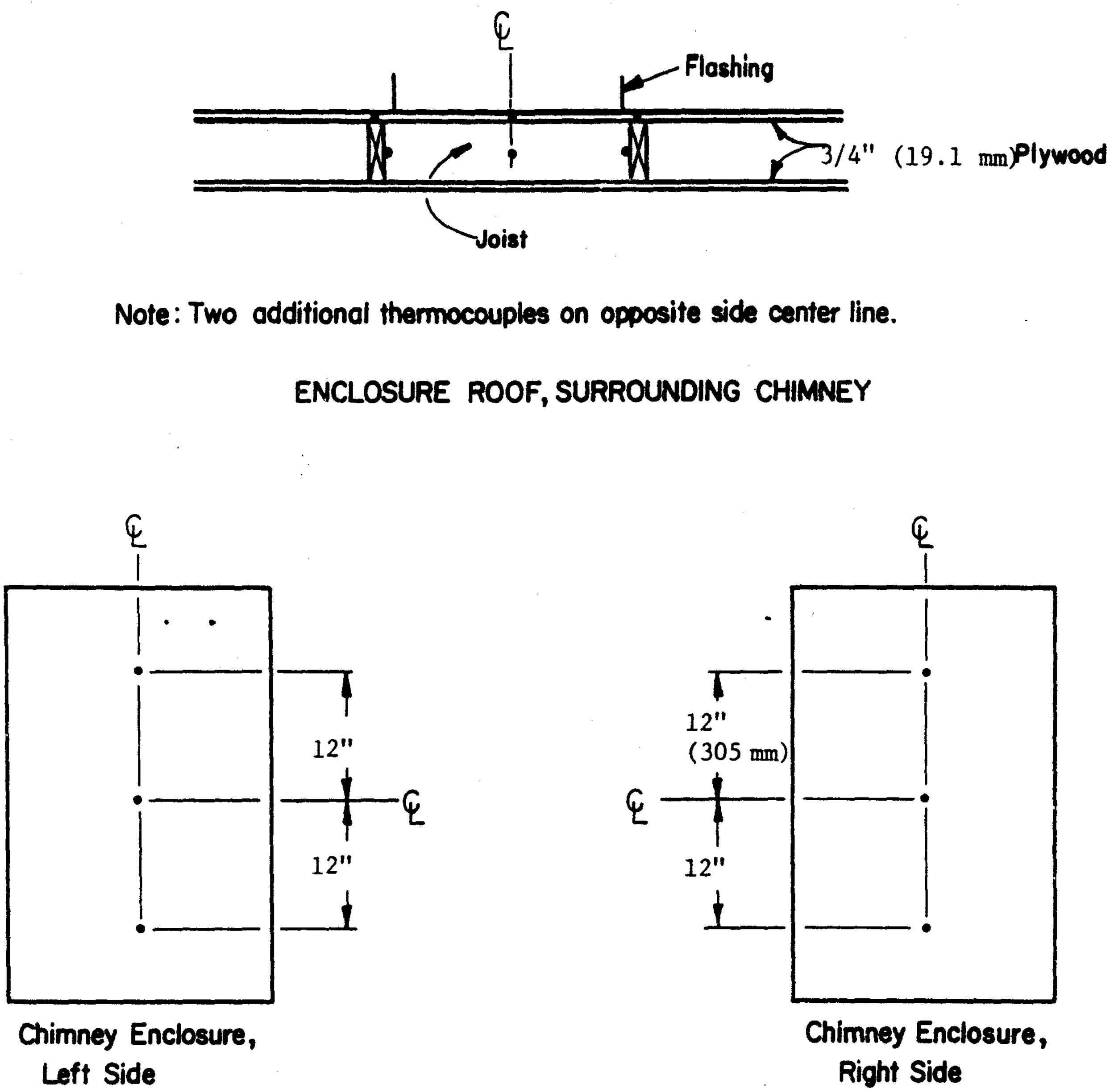
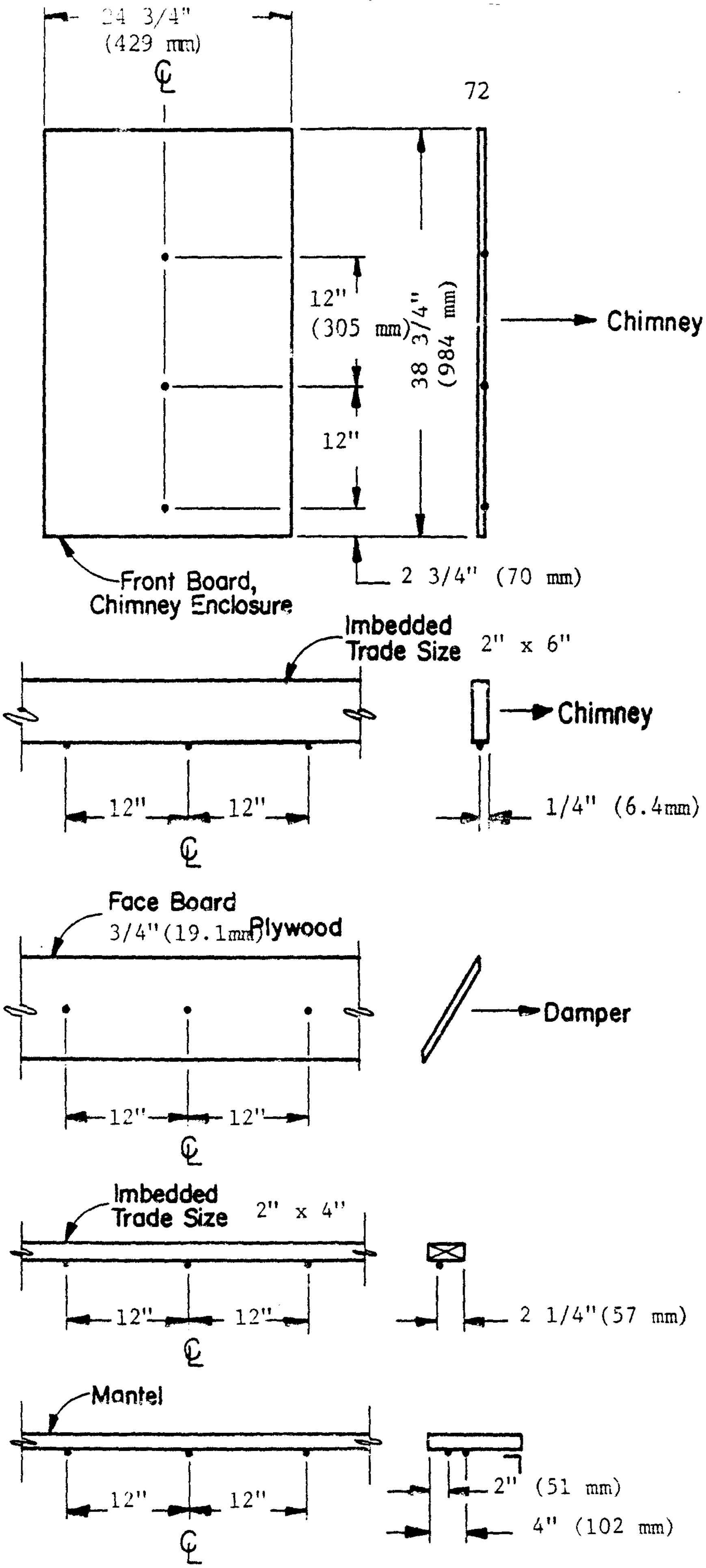


Figure 5.5 Masonry Thermocouple Locations, Chimney Enclosure



Metric Conversions, Lumber

Trade Size, Inches	Metric Equivalent, mm
2x4	44.4 x 95.3
2x6	44.4 x 140

Figure 5.6 Masonry Thermocouple Locations, Enclosure

Figure 5.7
MASONRY

THERMOCOUPLE LOCATION FOR FLUE GAS TEMPERATURE MEASUREMENT.

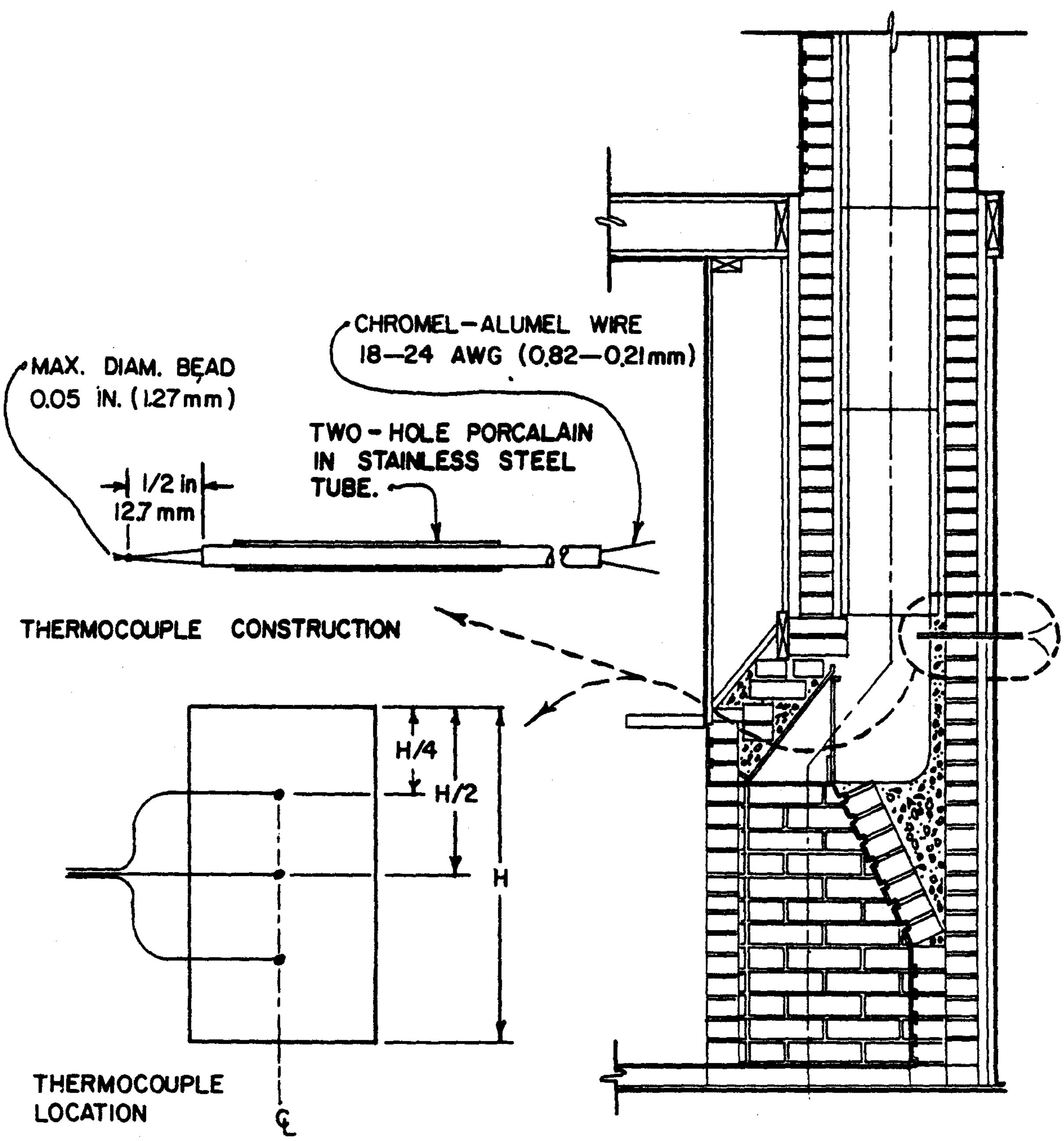


Table 5.1 Temperature Rises Above Ambient for Test in Masonry Fireplace (^{0}F)

C	T.C. Location	Brand fire No insert	Log fire Insert No. 1	Brand Fire Insert No. 5 (Non-positive flue connection)
1	Left side encl.	45	2	20
2	Left side encl.	46	6	36
3	Left side encl.	46	6	34
4	Left side encl.	4	-3	7
5	Left side encl.	54	1	17
6	Left side encl.	28	2	26
7	Left side encl.	27	1	32
8	Left side encl.	87	0	15
9	Left side encl.	58	3	17
10	Right side encl.	35	3	26
11	Right side encl.	40	-2	10
12	Right side encl.	34	1	14
13	Right side encl.	63	0	12
14	Right side encl.	42	0	28
15	Right side encl.	34	7	34
16	Right side encl.	53	-3	9
17	Right side encl.	49	0	23
18	Right side encl.	48	0	12
19	Back wall encl.	55	-3	6
20	Back wall encl.	44	-4	7
21	Back wall encl.	36	-4	6
22	Back wall encl.	56	12	56
23	Back wall encl.	45	6	27
24	Back wall encl.	48	1	11
25	Back stack encl.	68	11	57
26	Back stack encl.	56	14	65
27	Back stack encl.	68	18	67
28	Damper face board	74	13	45
29	Damper face board	71	19	57
30	Damper face board	98	19	74
31	Left top encl.	33	10	36
32	Left top encl.	24	6	27
33	Left top encl.	41	11	43
34	Left top encl.	23	7	28
35	Right top encl.	13	4	23
36	Right top encl.	20	6	29
37	Right top encl.	36	10	41

Table 5.1 Temperature Rises Above Ambient for Test in Masonry Fireplace (^{o}F) (Cont.)

C	T.C. Location	Brand fire No insert	Log fire Insert No. 1	Brand fire Insert No. 5 (Non-positive flue connection)
38	Right top encl.	34	8	40
39	Left chimney encl.	76	12	64
40	Left chimney encl.	75	—	62
41	Left chimney encl.	69	13	60
42	Right chimney encl.	69	—	61
43	Right chimney encl.	69	12	62
44	Right chimney encl.	67	12	67
45	Front chimney encl.	75	12	65
46	Front chimney encl.	80	13	67
47	Front chimney encl.	83	12	69
48	Roof plug	75	12	63
49	Roof plug	85	15	73
50	Roof plug	51	11	59
51	Roof plug	71	12	67
52	Roof plug	64	11	64
53	Roof plug	83	13	70
54	Roof plug	73	12	62
55	Roof plug	73	13	65
56	Sidewall	100	10	23
57	Sidewall	105	10	25
58	Sidewall	147	13	28
59	Sidewall	138	12	25
60	Sidewall	141	12	26
61	Sidewall	153	14	28
62	Floor	225	27	65
63	Floor	183	22	52
64	Floor	235	34	74
65	Floor	174	29	66
66	Floor	246	44	100
67	Mantel	190	67	88
68	Mantel	180	52	70
69	Mantel	188	57	79
70	Imbedded 2" x 4"	—	—	—
71	Imbedded 2" x 4"	—	—	—
72	Imbedded 2" x 4"	—	—	—
73	2" x 6"	88	19	75
74	2" x 6"	102	20	94
75	2" x 6"	77	13	61
76	Masonry	197	30	7
77	Masonry	162	25	106

Table 5.1 Temperature Rises Above Ambient for Test in Masonry Fireplace (^{o}F) (Cont.)

C	T.C. Location	Brand fire No insert	Log fire Insert No. 1	Brand fire Insert No. 5 (Non-positive flue connection)
78	Masonry	191	57	180
79	Masonry	201	50	176
80	Masonry	134	40	121
81	Masonry	117	9	31
82	Masonry	117	0	15
83	Masonry	109	83	197
84	Masonry	224	-1	21
85	Masonry	377	68	190
86	Masonry	800	82	141
87	Masonry	1017	34	63
88	Masonry	—	—	—
89	Masonry	—	—	—
90	Masonry	—	—	—
91	Masonry	—	—	—
92	Damper	583	188	236
93	Damper	653	263	284
94	Damper	665	228	287
95	Damper	565	150	209
96	Damper	860	240	490
97	Damper	742	223	398
	Flue Gas (Lower)	741	277	368
	Flue Gas (Upper)	665	191	171

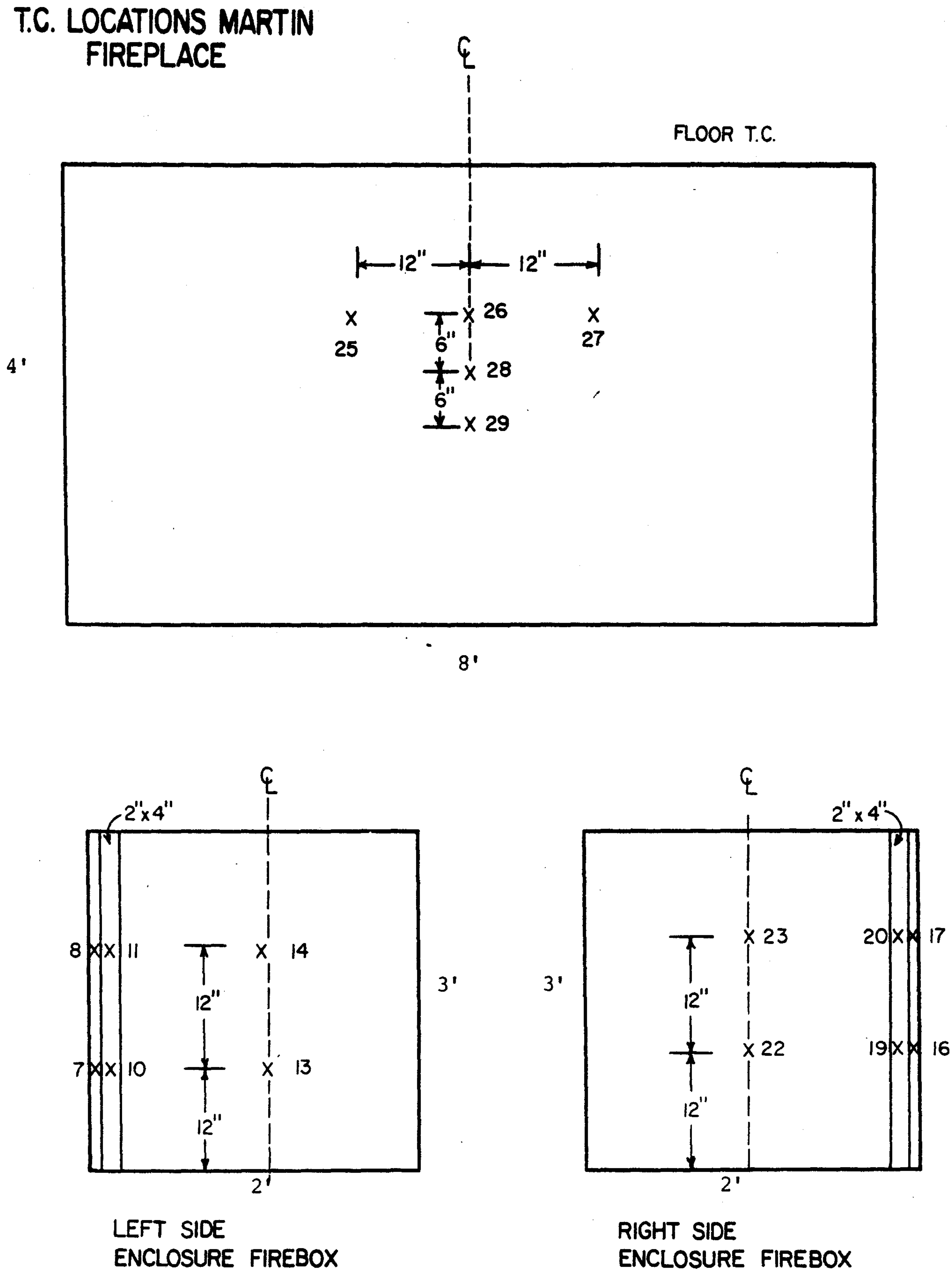


Figure 5.8 Thermocouple Locations for Manufactured Fireplace -- Fireplace No. F2

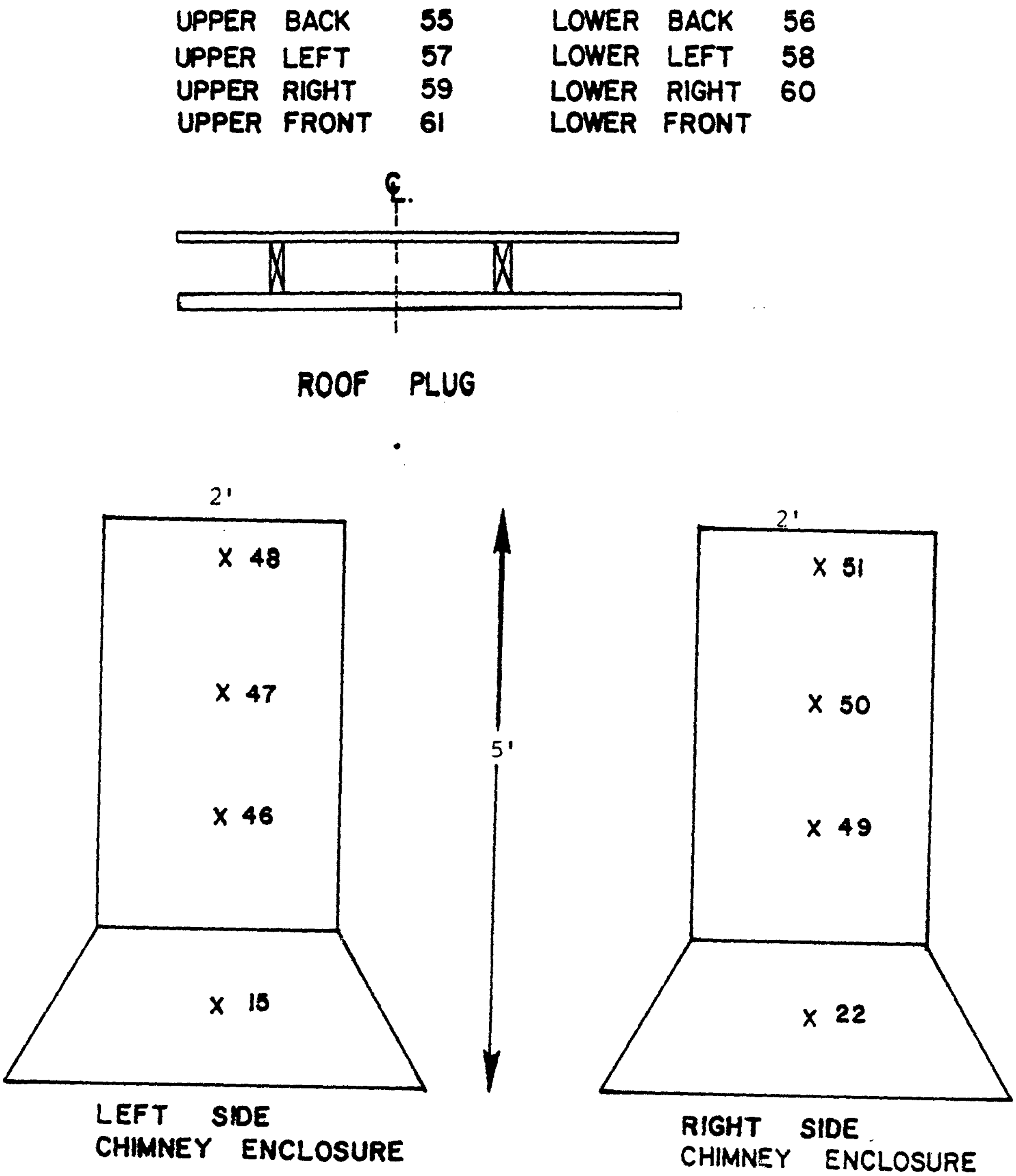
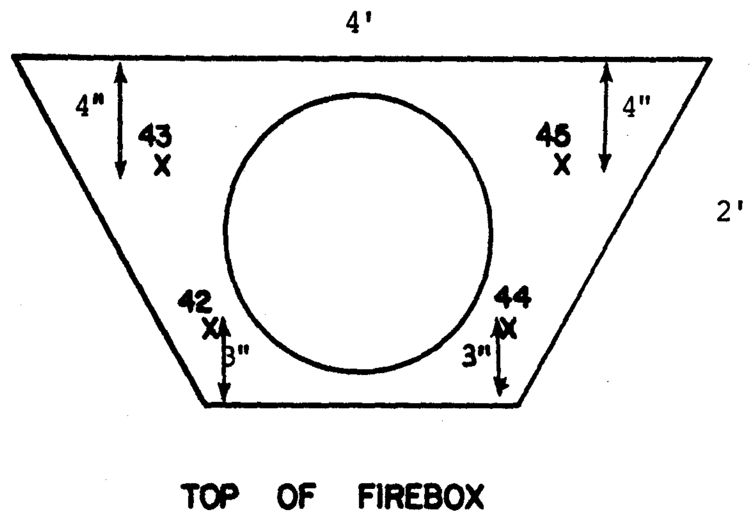


Figure 5.9 Thermocouple Location for Manufactured Fireplace -- Fireplace No. F2



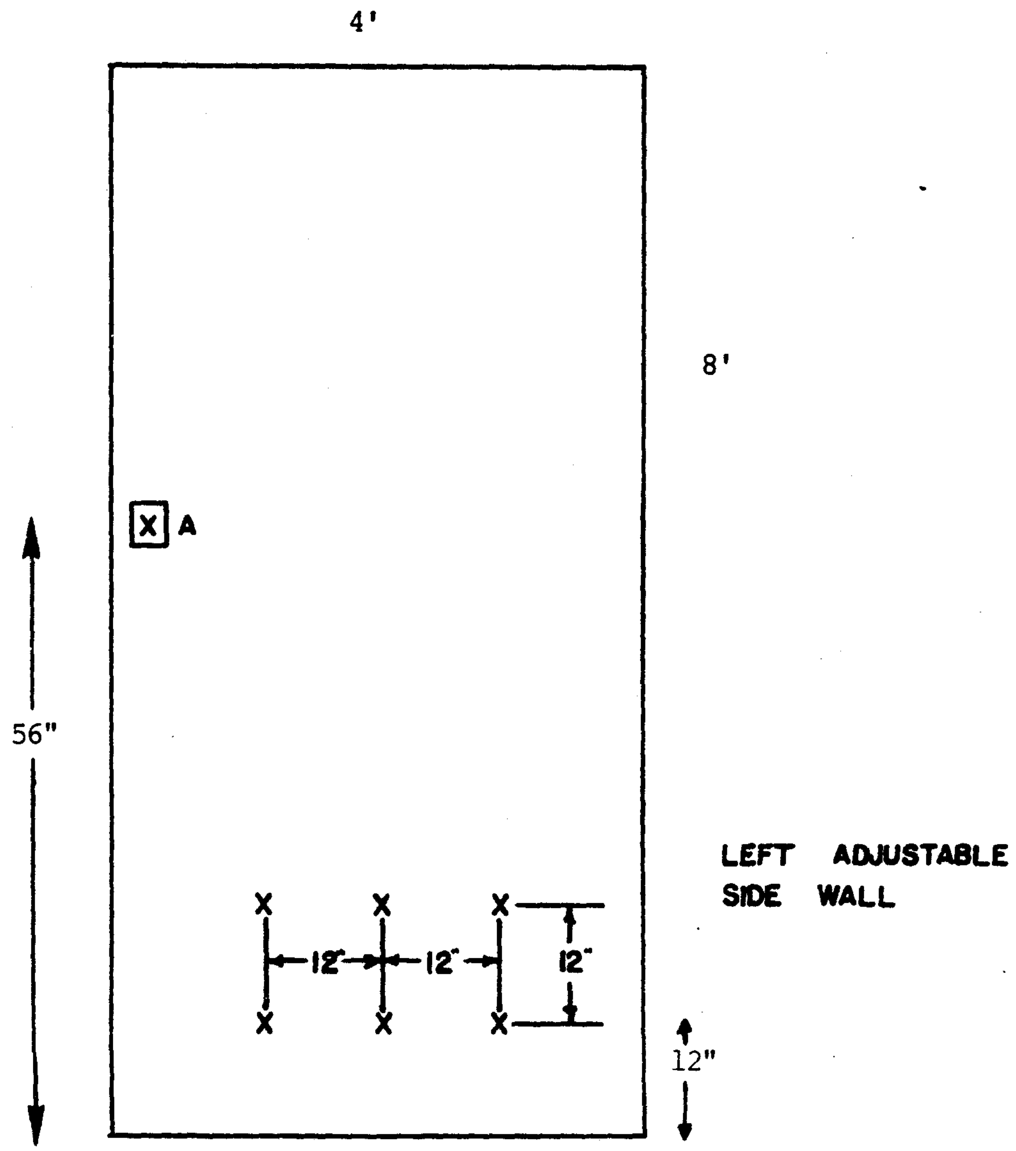


Figure 5.10 Thermocouple Location for Manufactured Fireplace -- Fireplace No. F2

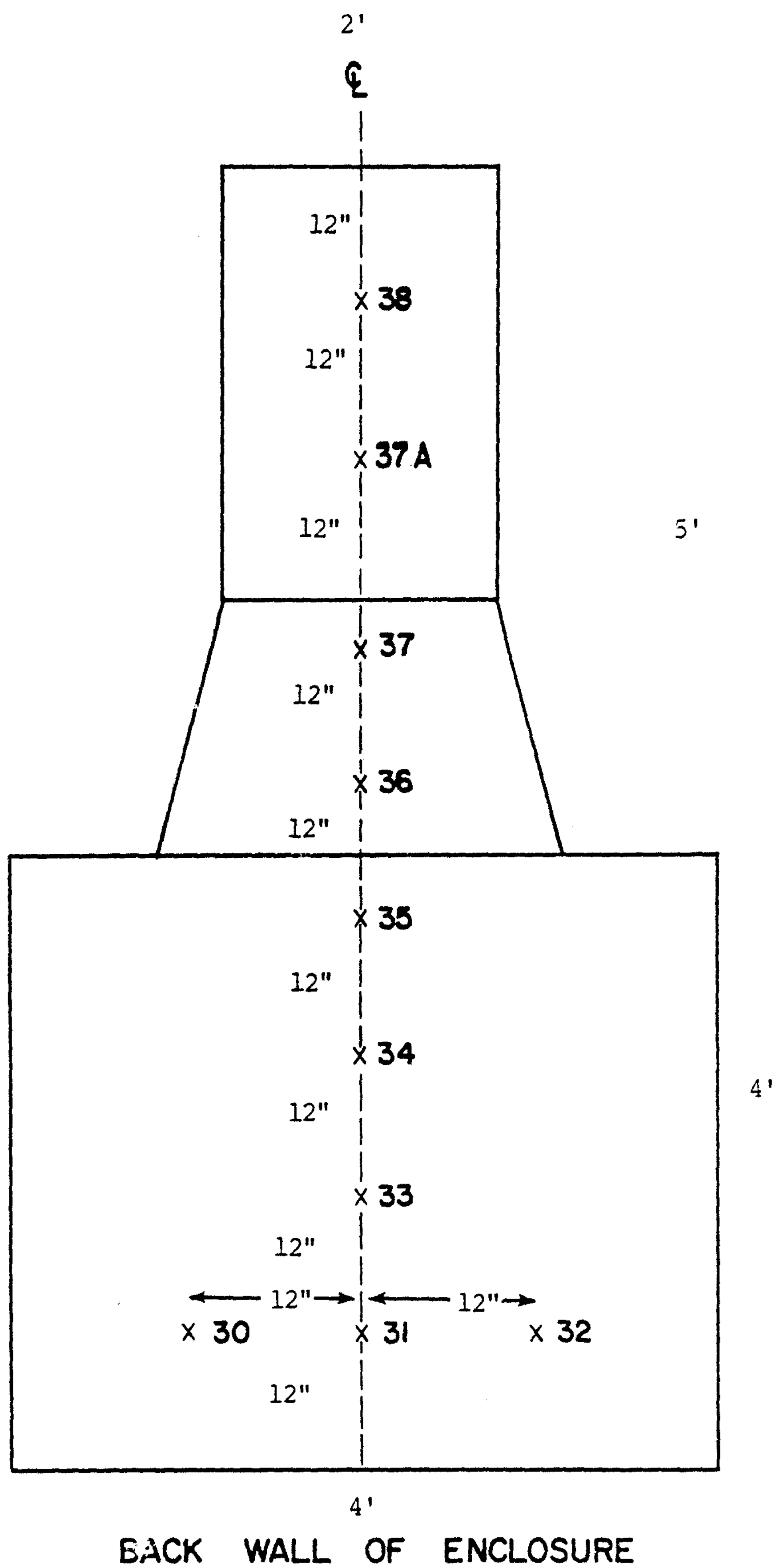
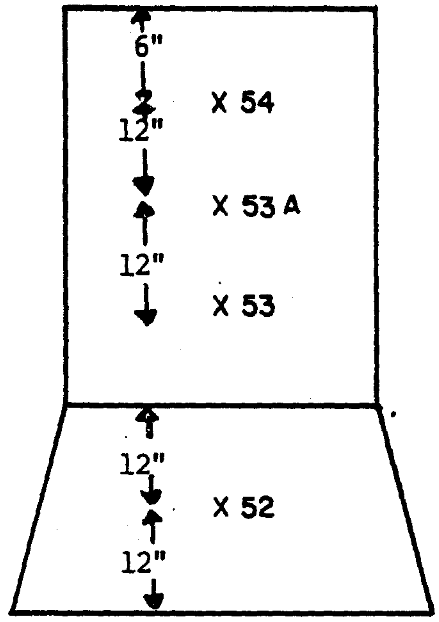
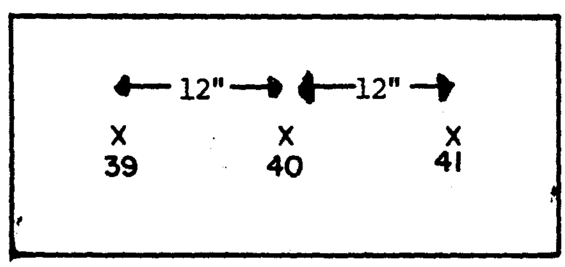


Figure 5.11 Thermocouple Location for Manufactured Fireplace -- Fireplace No. F2

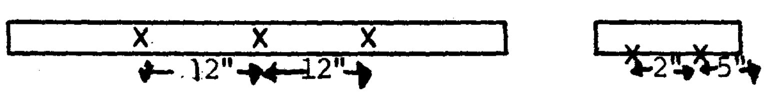


FRONT BOARD
CHIMNEY ENCLOSURE



DAMPER BOARD

LEFT FRONT 63
LEFT BACK 64
CENTER FRONT 65
CENTER BACK 66
RIGHT BACK 67
RIGHT FRONT 68



MANTEL

Figure 5.12 Thermocouple Locations for Manufactured Fireplace - No. F2 to be 1/3 the hearth area of the unit. Brand fires were used to simulate high firing conditions. More typical firing conditions were simulated by burning split oak cord wood or logs. The logs were at typical seasoned conditions, 20% to 30% moisture. During a brand fire one brand was added to the fire every 7½ minutes, however, during a log fire the logs were added as necessary to maintain a constant fire. During both type fires all air inlets to the unit were fully open.

5.3. Results and Discussion

Table 5.2 summarizes the tests that were run. The maximum temperatures measured (rise above ambient) are presented in Table 5.1 for the masonry fireplace and in Table 5.3 for fireplace No. F2.

The performance of the masonry fireplace without an insert was marginal. The temperature rises on the floor in front of the fireplace, the sidewall (both exposed to radiation from the fire), the mantel and the 2 x 6 inch contact with the masonry at the bottom of the chimney all equaled or exceeded the maximum rises recommended by Underwriters Laboratory. Those rises are 117°F for exposed combustibles and 90°F for unexposed surfaces. In addition many of the temperature rises on the plywood enclosure were only slightly below the recommended maximums. This does not mean that all masonry fireplaces are unsafe. This data is from one test on a fireplace that represents the minimal construction possible for a fireplace that could conceivably be acceptable by existing building codes. It should be pointed out that the mason retained to construct the fireplace repeatedly expressed his disapproval of the design.

Both insert tests run in this fireplace produced lower temperatures than did the test on the fireplace alone. The brand fire test was much hotter

Table 5.2 Summary of Thermal Tests

Run#	Fireplace	Insert	Type Fire
TM 1	Masonry	—	Brand
TM 2	Masonry	No. 1	Log
TM 3	Masonry	No. 5	Brand
TF 1	F2	—	Log
TF 2	F2	No. 2	Brand
TF 3	F2	No. 2	Log
TF 4	F2	No. 3	Log
TF 5	F2	No. 5	Log

Table 5.3 Temperature Rises Above Ambient For Test in Manufactured Fireplace F2 (°F)

C	T.C. Location	log fire No insert	Brand fire Insert No. 2	log fire Insert No. 2	log fire Insert No. 3	log fire Insert No. 5 (Non positive flue connection)
21	Left side enclosure of firebox 1 ft' on 2 x 4	11	11	-1	5	0
22	Left side wall 2' up middle	43	43	21	18	16
23	Left side wall 2' up right	33	39	17	19	12
24	Left side wall 1' up right	25	38	12	8	10
25	Left side wall 1' up middle	33	33	17	5	14
26	Front face board Firebox left	26	16	25	29	20
27	Front face board Firebox middle	42	80	37	67	38
28	Front face board Firebox right	27	64	30	38	27
29	Left side Enclosure Firebox 3' up end	6	13	5	10	7
30	Floor left front	73	87	33	18	46
31	Floor middle front	92	138	60	27	73
32	Left side enclosure firebox 3' up 2 x 4	2	22	-2	9	0
33	Left adjustable sidewall 1' up	16	31	10	15	7
40	Left adjustable sidewall 2' up	51	135	14	76	11

Table 5.3 Temperature Rises Above Ambient for Test in Manufactured Fireplace F2 (°F) (Cont.)

C	T.C. Location	log fire No insert	Brand fire Insert No. 2	log fire Insert No. 2	log fire Insert No. 3	log fire Insert No. 5 (Non positive flue connection)
41	Left side enclosure firebox end 2' up	38	140	14	63	12
42	Left side enclosure firebox 1' up right	12	115	-4	56	-3
43	Left side enclosure firebox 2' up right	21	114	0	57	-1
44	Backwall enclosure bottom left	26	114	1	59	-1
45	Left side enclosure firebox 2' up 2 x 4	32	117	10	61	6
46	Left side enclosure firebox end 1' up	27	110	7	64	8
47	Floor 12" back	53	143	38	78	42
48	Floor 6" back center	68	166	50	82	59
49	Floor right	81	174	51	73	48
50	Back of fireplace 2' up	17	20	-2	2	-2
54	Right side enclosure firebox 2 x 4 1' up	-3	0	-8	0	-4
55	Right side enclosure firebox 2 x 4 2' up	46	35	8	23	7
56	Right side enclosure firebox end 2' up	50	45	11	39	13
57	Right side enclosure firebox end 1' up	55	41	13	28	8
58	Ceiling right up	22	22	2	6	1

Table 5.3 Temperature Rises Above Ambient for Test in Manufactured Fireplace F2 (^{o}F) (Cont.)

C	T.C. Location	log fire No insert	Brand fire Insert No. 2	log fire Insert No. 2	log fire Insert No. 3	log fire Insert No. 5 (Non positive flue connection)
59	Ceiling front down	34	24	5	5	1
61	Left side enclosure firebox 2' up	28	27	6	5	3
62	Back of fireplace 3' up	25	34	3	4	1
63	Right side of chimney encl. middle	14	18	4	5	1
64	Back 4' up	21	35	7	7	4
66	Left side top of firebox back	17	25	2	13	1
67	Left side top of firebox front	25	50	17	37	17
68	Right side of firebox back	44	44	11	9	7
70	Left side chimney enclosure bottom	17	24	2	3	-1
71	Front board chimney enclosure middle	26	22	5	9	1
72	Right side chimney enclosure bottom	16	29	1	5	0
73	Back 6' up	17	20	1	2	-1
74	Back 5' up	15	18	0	2	-1
75	Front board of chimney encl. middle	14	20	0	4	0
76	Ceiling right up	45	—	7	4	2
77	Ceiling front up	31	25	4	5	1

Table 5.3 Temperature Rises Above Ambient for Test in Manufactured Fireplace F2 (°F) (Cont.)

C	T.C. Location	log fire No insert	Brand fire Insert No. 2	log fire Insert No. 2	log fire Insert No. 3	log fire Insert No. 5 (Non positive flue connection)
78	Right side of firebox end 3' up	7	24	6	19	1
79	Right side of fire-box end 3' up	4	12	0	12	0
80	Left side of chim-ney enclosure 3' up	21	34	4	6	2
81	Front of chimney enclosure 3' up	14	20	3	6	0
82	Back Right 1' up	16	21	-4	2	-4
83	Mantel left front	66	165	104	69	63
84	Mantel left back	51	162	107	70	65
85	Mantel middle front	72	206	116	89	69
86	Mantel middle back	52	200	118	88	69
87	Mantel right front	60	203	102	73	47
88	Right side encl. firebox 1' up middle	53	192	111	72	46
89	Mantel right back	-2	0	-6	-2	-3
90	Left side of chimney enclosure 2' up	22	31	4	8	-2
91	Back G 1/2 ft. up	15	18	2	4	0
92	Back 7' up	27	37	5	7	2
93	Ceiling back up	24	34	5	7	2
94	Ceiling left down	21	31	4	7	1
95	Ceiling left up	26	33	4	7	1
96	Ceiling back down	23	34	3	6	1
97	Right side of fire-box 3' up middle	47	59	13	11	9

Table 5.3 Temperature Rises Above Ambient for Test in Manufactured Fireplace F2 (^{o}F) (Cont.)

C	T.C. Location	log fire No insert	Brand fire Insert No. 2	log fire Insert No. 2	log fire Insert No. 3	log fire Insert No. 5 (Non positive flue connection)
98	Right side of fire-box w' up middle	23	25	0	5	0
99	Back middle 1' up	4	8	-6	-1	-4
—	Flue gas lower	515	961	485	318	549
—	Flue gas upper	505	989	488	313	488

than the log fire test. This resulted in part because the effective hearth area was reduced by installing the insert. The lower temperatures on the floor, mantel, and sidewall result because the insert does not radiate heat outside the fireplace as well as the open fireplace. In general, the tests with inserts showed lower temperature rises than those without. However, it should be kept in mind that larger inserts can produce higher temperatures; hence, smaller inserts (smaller fires) inherently operate at lower temperatures.

The tests on fireplace F2 repeated the pattern shown for the masonry fireplace. That is, the inserts with the larger hearth areas produced higher temperatures in general. The temperatures on the mantel do not reflect this trend, probably because the mantel temperature is dependent on the shape of that portion of the insert that extends from the front of the fireplace opening. The brand fire test run on insert No. 2 produced much higher temperatures than did the log fire test.

It is interesting to note that the flue gas temperatures were higher with an insert for fireplace F2 while the flue gas temperatures for the masonry fireplace decreased with the use of an insert. This indicates that less dilution air was leaking into fireplace F2 than into the masonry fireplace. Also, the masonry chimney was larger in cross section which produced a lower flue gas velocity, and hence, provided more time for cooling. This coupled with the relatively poor insulating qualities of the masonry could account for some heat loss from the flue gases in the masonry chimney.

6. Conclusions and Recommendations

Creosote tests and thermal performance tests were run on several insert-fireplace combinations. The following comments are made:

1. The tests to measure relative creosote production emphasized the difficulty of producing creosote under laboratory conditions. Perhaps the high ambient temperatures prevalent during the tests account for these results.

2. The creosote tests do indicate that inserts can be operated without undue creosote production. Note especially the two field tests; neither of the units observed produced significant creosote deposits during a full heating season.

3. Creosote production is determined primarily by the mode of operation of the appliance, rather than by the type and moisture content of the wood burned.

4. The minimal masonry fireplace exhibited little thermal protection for the combustible materials surrounding it. Perhaps this is not the best fireplace design to use for a fireplace insert test facility; however, the fireplace used was built according to existing standards and similar units (or worse) could exist in many homes.

5. The most significant factor to an insert's performance appears to be the hearth area which determines the maximum burn rate. The larger inserts certainly produced higher temperature rises in the tests than did the smaller inserts. This indicates that a large percentage of the heat released is being used to heat the fireplace as opposed to heating the room. Note that fans were not in operation during the thermal tests; hence, the inserts were not operating under conditions to yield optimum efficiency.

It is recommended that more tests be performed to study the relative creosote production for the various insert-fireplace combinations. Perhaps operating the units in a colder environment (even if an artificial environment must be provided) and/or running the tests for extended periods of time, i.e., for months rather than weeks, would be fruitful.

The masonry fireplace used should be reviewed. It is obvious that the particular fireplace design utilized will greatly affect the performance of the inserts tested. The test fireplace does meet code requirements; however, if it is substantially less adequate than the typical fireplace in place in American homes, perhaps a more typical fireplace would be reasonable for an insert test facility. The question remains as to just how most masonry fireplaces are actually built. Very clearly many inserts are being used safely in masonry fireplaces.

More thermal tests for inserts in manufactured fireplaces are needed to ensure that a sufficient number of combinations has been sampled. The data taken in this test program did not indicate any serious problems. However, only a very few combinations were studied, and none of the tests run involved any modifications to the basic fireplace. It is not unreasonable to expect a homeowner to modify a fireplace to make installation of an insert possible or easier. Zero clearance fireplaces are dependent on the insulation/cooling designed into them and seemingly unimportant modifications can render the units unsafe. The only safe conclusion is that the use of fireplace inserts in manufactured fireplaces must be evaluated on an individual basis, and this evaluation should involve participation by the fireplace manufacturer.

Finally, because the insert used for the field tests suffered several glass breakages, it would be good to run a series of tests on units with glass doors while one glass was not in place. Of course, there may be a problem of sparks or embers falling from the opening as with any open fire. However, of more interest would be the rate of burn, and hence, rate of heat output due to the additional combustion air supply.

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APPENDIX A

Fireplace Insert Questionnaire

FIREPLACE INSERT QUESTIONNAIRE

Please return this sheet, along with any brochures or drawings, to:

Dr. Timothy T. Maxwell
Auburn University
Department of Mechanical Engineering
Auburn, AL 36830

Please check the appropriate description and fill in the requested information to all questions that apply. Write in additional information and use additional sheets as needed.

MANUFACTURER NAME ______________________________

ADDRESS ______________________________

____

PHONE NUMBER ______________ CONTACT PERSON ______________

MODEL NUMBER ______________________________

I. Construction Details

A. Enclosure

_____ Full firebox enclosure

_____ Single-box construction
_____ Box-in-a box construction

_____ Partial firebox enclosure (bottom open to ash pit, etc.)

_____ Part of firebox enclosure protrudes past fireplace opening

_____ Number of inches

_____ Other outstanding features (describe)

_____ Are andirons or a grate included

B. Doors

_____ Airtight

_____ Semi airtight

_____ Very loose

C. Flue Connector

_____ Number of openings

_____ Shape of openings (round, square, etc.)

_____ Location of openings (top, rear, etc.)

_____ Is there an airtight connection between firebox and chimney

D. Air Intake

_____ Thermostatic control; type ____________________________

_____ Manual control

_____ Number of air inlets

_____ Location of air inlets

_____ Is combustion air routed through ash grate

E. Room Air Circulation System

_____ Natural convection or fan forced convection

_____ Location of fan

_____ How many sides of the firebox are exposed to circulating air

_____ Are baffles or deflectors used to direct air flow

_____ Is extra heat transfer surface provided by tubes, fins, etc.

_____ If so, what size and where are the fins, tubes, etc.

II. Materials

A. Firebox

_____ Plate steel; thickness __________ inches

_____ Cast iron; thickness __________ inches

_____ Sheet metal; thickness __________ inches

_____ Other; thickness __________ inches

B. Outer Enclosure

_____ Plate steel; thickness __________ inches

_____ Cast iron; thickness __________ inches

_____ Sheet metal; thickness __________ inches

_____ Other; thickness __________ inches

C. Doors

_____ Steel

_____ Cast iron

_____ Glass Inserts

_____ Gasket around door or door facing

_____ Other

D. Flue Connector

_____ Steel

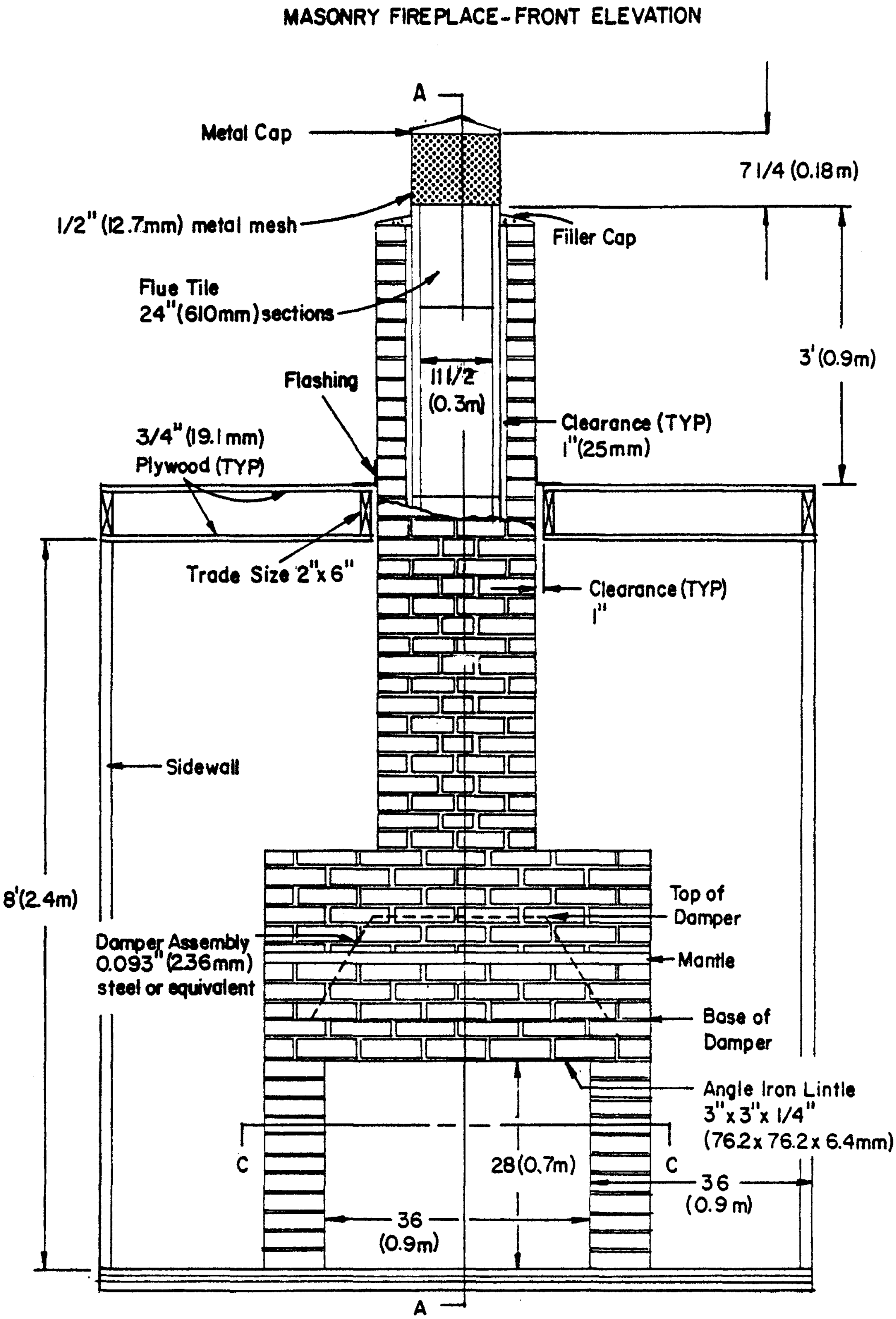
_____ Cast iron

_____ Other

_____ None

APPENDIX B

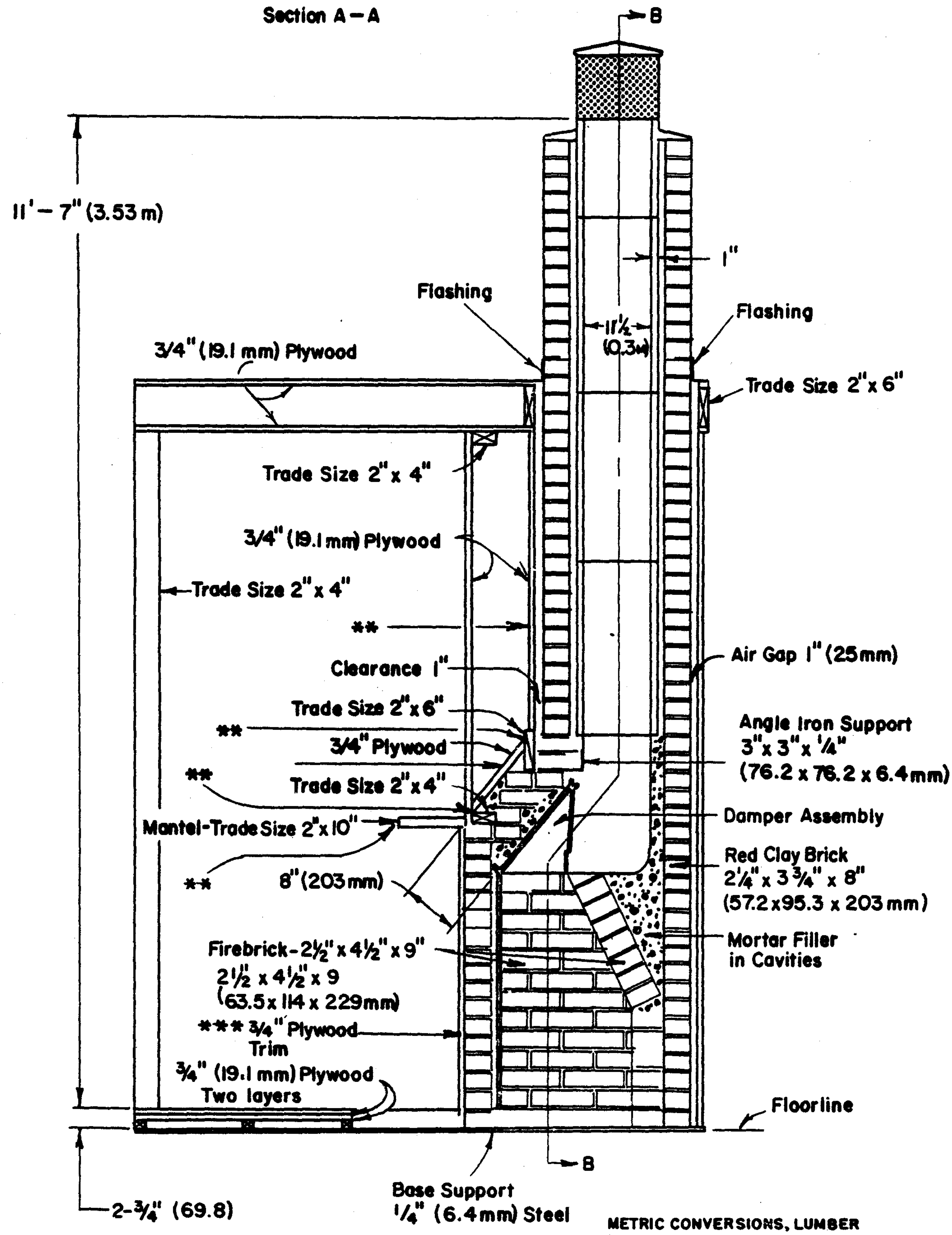
Diagrams of Masonry Fireplace



Metric Conversions, Lumber	
Trade Size Inches	Metric Equivalent mm
2 x 6	44.4 x 140

Note: Plywood enclosure not shown
*See Reference 14 for dimensions

Figure B.1

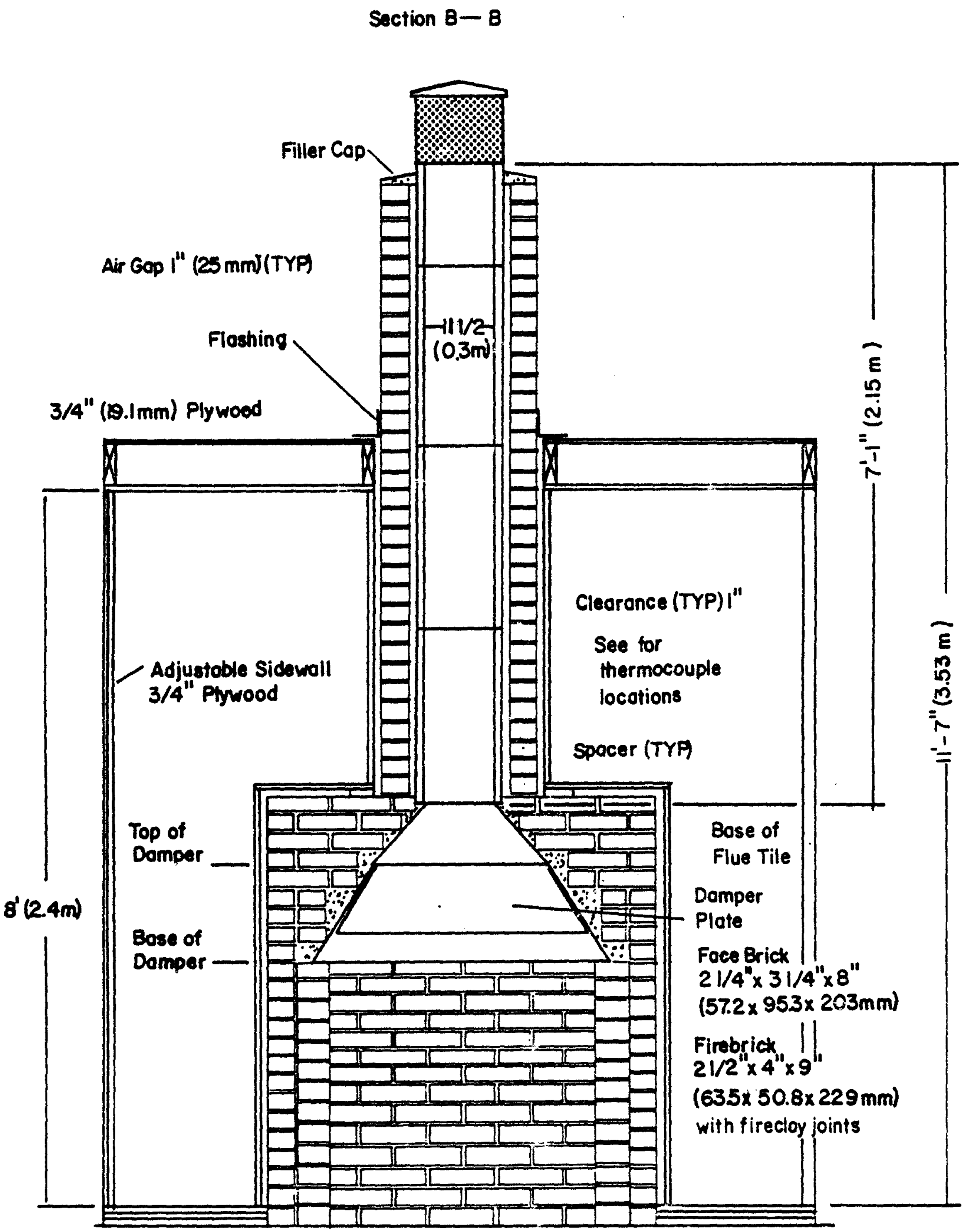


*For details on dimensions, see Reference 14.

METRIC CONVERSIONS, LUMBER

TRADE SIZE INCHES	METRIC EQUIVALENT MM
2 X 4	44.4 X 95.3
2 X 6	44.4 X 140
2 X 10	44.4 X 241

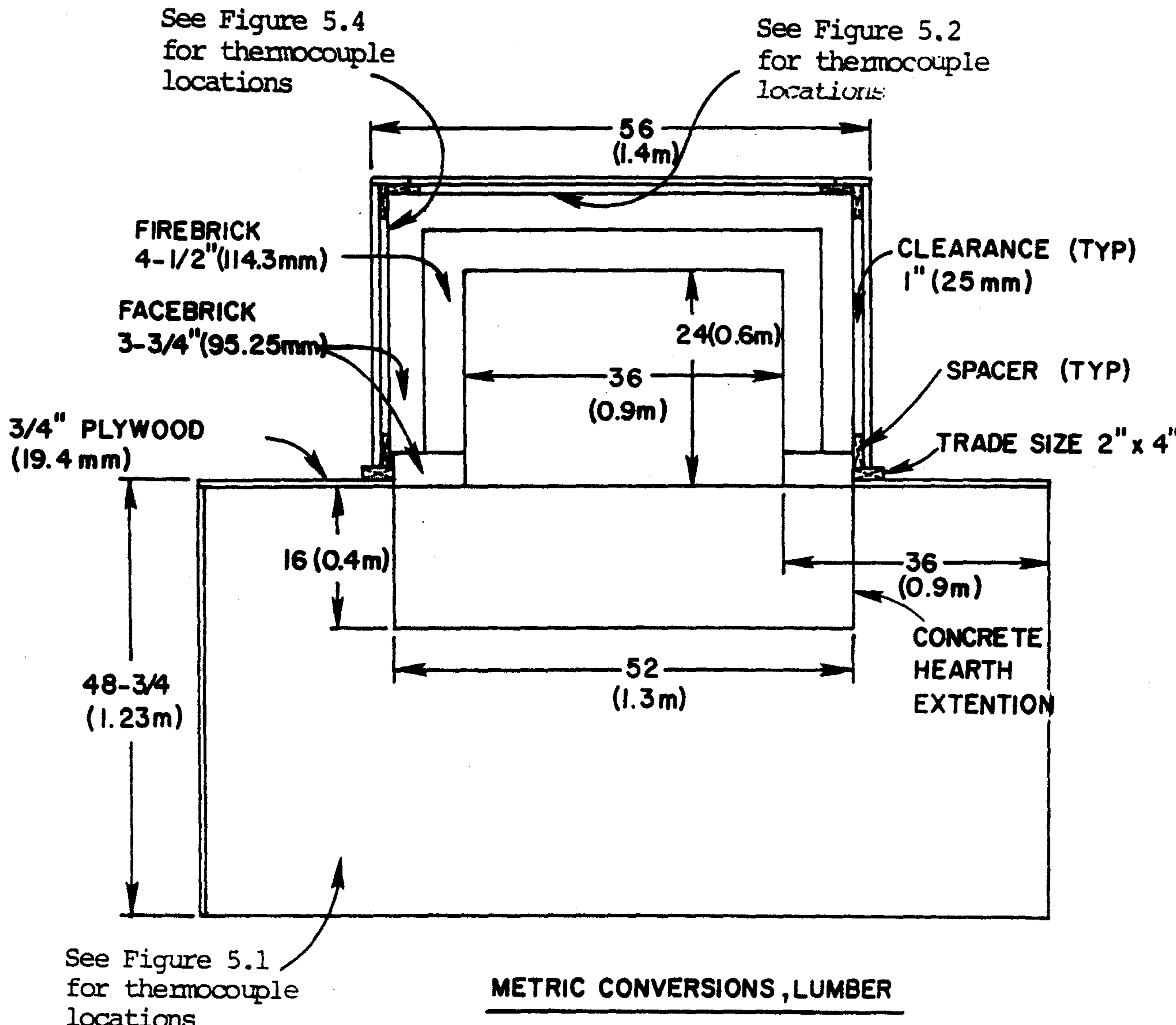
Figure B.2



*For details on dimensions see Reference 14.

Figure B.3

SECTION C-C OF FIGURE B.1



METRIC CONVERSIONS, LUMBER

TRADE SIZE INCHES	METRIC EQUIVALENT mm
2 x 4	44.4 x 95.3

Figure B.4

NBS-114A (REV. 2-80)

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5. AUTHOR(S)

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6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

Estimates indicate that there are between 15 and 30 million fireplaces in existence in the United States. The use of fireplace inserts could provide primary heating sources for many of the homes in which they are located. This report presents the results of a testing program to quantify safety problems in the areas of chimney creosoting, efficiency and thermal performance of the inserts when used in masonry and factory-built fireplaces.

The most important factors affecting creosote formation were found to be appliance type, moisture content and wood type. However, significant levels of creosote were formed with all fuels tested. This indicates that there is no "safe" wood to burn which will not produce creosote. Further, it emphasizes the necessity of routine maintenance on the part of homeowners who heat with wood.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

Chimneys; creosote; fire safety; flues; heating equipment; stoves; temperature measurements; tar; wood

13. AVAILABILITY

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